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A generic group technology classification and coding scheme for furniture production /

Heejoon Kim
Lehigh University

A GENERIC GROUP TECHNOLOGY CLASSIFICATION AND CODING SCHEME FOR FURNITURE PRODUCTION

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Heejoon Kim

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(date)

Nicholas G. Odrey
Professor in Charge

S. E. Kane
Chairman of Department

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ABSTRACT

The majority of the developed and successfully implemented Group Technology(GT)-based classification and coding systems are mainly based on the metal-working industry. However, it has been found that there are significant differences in nature between the metal-working industry and other nonmetal-working industries, particularly a furniture industry in this research. The essence of the difference can be viewed in two different ways, i.e. from the design point of view and the process point of view. The intent of this research is to develop a generic GT coding system for furniture production. A case company is used to illustrate applications of the proposed GT code. The proposed GT code basically consists of two parts (design and process parts). It is found that the design features of the basic components in the furniture industry are relatively simple compared with the metal-working industry. There are less variations in design and typically only one kind of material, the wood, is dominantly used, whose properties are also relatively simple compared to metals. On the other hand, attention should be paid to some of other features such as the product families, the hierarchical level of the products, and the function of the products in designing a

system for the furniture industry. The major flow of the processes of the furniture industry is assembly process oriented, while the dominant processes in the metal-working industry are cutting operations. This difference calls for a different approach in designing a process part of a GT code for the furniture industry. The functional operation segments (FOS) method proposed in this research investigates interrelationships of the processes inherent in the furniture production and compacts numbers of processes into a code with a limited number of digits while providing sequential order of processes. The process code developed by the FOS method can potentially not only interface with a variant Computer-aided Process Planning (CAPP) system, but overcome one of its major shortcomings, the inflexibility.

I. Introduction

Group Technology (GT) and Computer-Aided Process Planning (CAPP) are two of the rapidly developing manufacturing areas intended to cope with today's dynamically changing manufacturing environment. The concept of GT is based on similarities of a family group or process routing. Part classification and coding systems which classify and code parts to form a family group is the critical point for successful implementation of GT. The success of CAPP is dependent on a company's standardized decision-making logic about process planning. Process planning logic requires extensive knowledges about not only parts' features but the machine processes necessary for their fabrication. Given that a classification and coding system contains much of the knowledges required for a CAPP system, it is advantageous if a classification and coding system can be interfaced with a CAPP system to form a part of computer-integrated-manufacturing (CIM) system. In other words, a classification and coding system can serve as a front-end for a CAPP system. The knowledge base required for a CAPP system and the associated structure on how to represent this knowledge base is essential for the successful development of a classification and coding system for both

GT and a front-end CAPP system.

DCLASS is a commercially available general-purpose information handling and decision making system [5]. Unlike other classification and coding systems, the main strength of DCLASS is it's high flexibility to be tailored to fit each user's needs. The flexibility inherent in the DCLASS software served as the impetus for this thesis in aiding the development of a classification and coding system as a front-end to a CAPP system. The general structure of this thesis is summarized in the following paragraphs.

Initially, a literature review of the two basic concepts governing this thesis is presented. The two basic component concepts include: 1) Group Technology, 2) Computer-Aided Process Planning.

For obtaining best results from a classification and coding system, it should embrace all the existing items within the company and reflect all the necessary features about those items. Therefore, it cannot be overemphasized of the necessity to find the right features of parts and processes and determine which features should be reflected on the classification and coding system. As part of this thesis, the process of knowledge acquisition to develop the classification and coding system will be shown via a case company project. The case company is a furniture producer which previously has not been involved in GT. The knowledge of parts will have two features: (1) design features and (2) process features. These features can be obtained basically by two different methods. The first method entails an extensive interview of relevant in-house people. By interviewing the field experts, it is hoped that any and all undocumented company's standards can be obtained. The second method relies on published documents, which include blue prints, process route sheets, and standard analysis procedure. Documents can also serve as good references for a systematic approach to the knowledge acquisition relevant to such topics as process flow. Based on the knowledge acquired via the two prescribed methods, this thesis is directed toward developing the necessary knowledge base structure and the final code structure of the classification and coding system for furtuniture production using DCLASS.

The CAPP system requires basically six types of knowledge bases(KB), namely KB for workpieces, KB for type forms, KB for technological sequences, KB for tools, KB for machine tools, and finally KB for fixtures. In addition this thesis investigates the interface between the classification and coding system and the knowledge base of a CAPP system based on the developed GT-based code for furniture production.

II. Objective of the Research

The main objective of this research is to develop a classification and coding system for a successful GT implementation to a non-metal working company, using a furniture company as a case company. Furthermore, the resulting classification and coding system should be structured to serve as an input to a CAPP system.

Because DCLASS is a general-purpose information handling and decision making system with a capability for being highly tailored and customized, it was chosen as the basis for developing a classification and coding system in this research.

III. Literature Review

3.1 Group Technology

3.1.1 Introduction to Group Technology

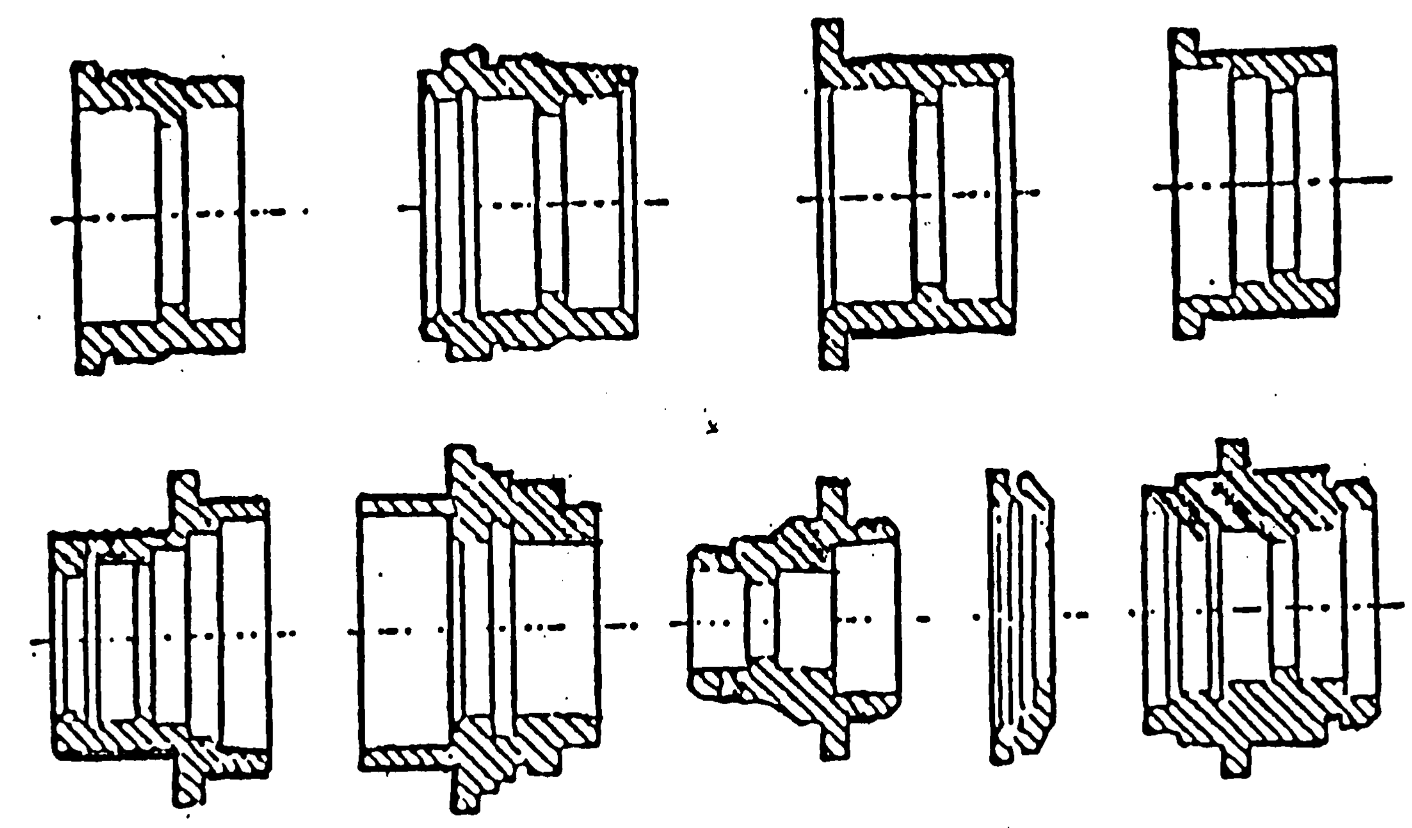
General Concept: Conventional manufacturing systems of today are challenged by needs and trends and forced to cope with today's dynamically changing manufacturing environment. Integral to this changing environment is the need for capability to produce diversified products. The trend in such an environment requires producing small manufacturing batch sizes efficiently and economically.

The conventional approach to small or medium size batch production is the use of a functional layout where similar machines are grouped together according to type. Each product, dependent on its process routing, has to pass through all or some of the machines. Materials flow are extremely complicated in this type of machine arrangement. Typically, a reservoir of work has to be kept ahead of each machine group to help increase the machine utilization. This results in high work-in-process inventories and long through-put time with subsequent uneconomical consequences [47, 48, 61].

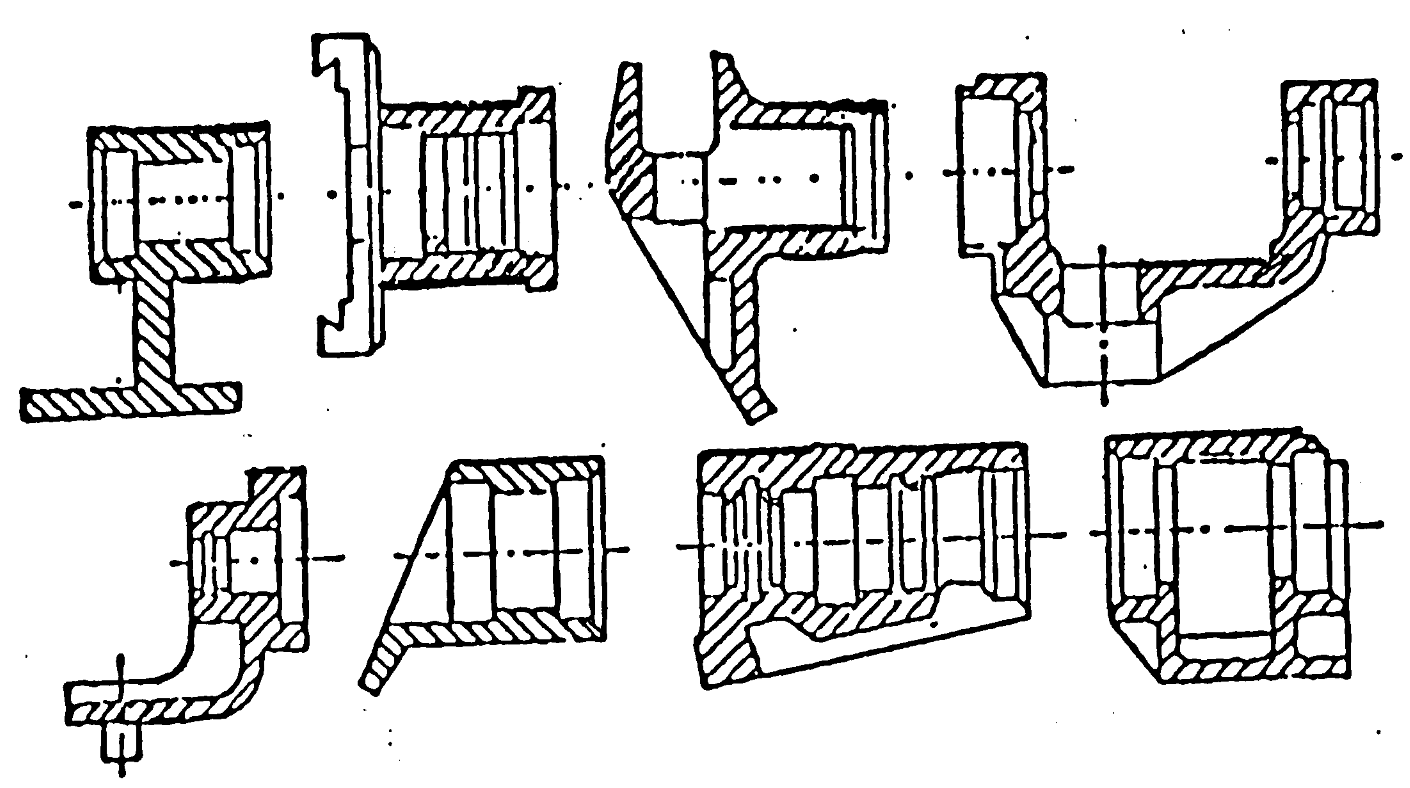
One approach to the problems presented by functional layouts is to apply successful mass production technique to batch type production systems. However, this can only be achieved economically when the quantity of production units is reasonably large enough to justify the analysis and design of the manufacturing system. This quantity of production units represents a group or family based on somewhat similar parts, which are chosen according to their shapes, sizes, and production methods (Figure III.1) [2, 21, 22, 34, 37, 55, 58, 59, 61, 63].

Group Technology is a philosophy which takes advantage of similarities of part design and/or process similarities to bring some of the economies of mass production to today's batch-oriented manufacturing system. It's primary aim is to obtain increased efficiency and economy which are usually associated with large scale mass production system [1, 12, 30, 31, 51].

The first GT concept was introduced in the early 1900's by Taylor in U.S. [33], and a Russian, S.P. Mitrofanov, applied the concepts to the metal-working industry in 1940 [49]. Since then, numerous researchers have developed GT classification and coding systems which have been widely accepted and successfully implemented in industry [10, 11, 12, 13, 25, 35, 36, 50, 51, 60]. Most of the GT systems developed were based on the metal-working industry, and accordingly, most of the successful GT



(a) Part family with similarity in shapes



(b) Part family with similarity in production operations

Figure III.1 Examples of Part Family [32] implementation cases can be also found in that area. However, the process of designing GT classification and coding systems differs between the metal-working industry and other non-metal-working industries such as the furniture industry.

The main difference between the two industry classifications is the way that a part is processed. In the metal-working industry, an object to be classified and coded is the part or component which is made of homogeneous material. The most dominating machine process is a metal-cutting operation, such as a drilling, cutting, or milling operation. Part material properties are complex and play an important role in selecting processes or tools. Designs are diversified and have numerous features.

In the furniture industry, the dominating operations are assembly operations which assemble raw materials to form a component and again assemble components to form subassemblies, etc. The features of the component are relatively simple and have less variations compared with parts in a metal-working industry. In addition, most of the components are made of wood and their properties are not as complex as metals and do not have much influence on selecting the processes or tools. Because of the assembly-oriented nature of the furniture industrys' processes, special considerations, such as the level of part where it is positioned in the assembly hierarchy, the definition of terminology to define the hierarchical level of parts, and the various operations to make parts and assemble parts, should be made. As a result, the most commercially available classification and coding systems designed and tested based on the metal-working industry are not typically compatible to the furniture industry.

Incentives for Group Technology: Since the early 1970's, the needs for diversified products have continuously increased, and there has been generated a need for efficient, diversified, small lot quantity production systems. According to the statistics acquired by Merchant [47], 75 percent of all industrial parts manufactured in the U.S. metal-working industry are on the small lot base and the average lot size is less than 50 pieces.

It also has been reported [17] that in batch type metal working shops, only 5 percent of total production time is spent on machine tools, while the remaining 95 percent of the total time was spent for moving the parts and waiting for machining processes in the shop. Such time losses are generally considered the major reason for the inefficiencies inherent in batch type production system.

Group Technology is one technique which is intended to solve the problems inherent in batch type production system and atain the goal of today's manufacturing trend, that is, to efficiently produce diversified products on small-lot base.

A continuing trend in U.S. manufacturing systems is the automation of the factory via NC machines, Industrial Robotics, CAD/CAM, etc. While these machines or techniques offers a great deal of flexibility without sacrificing efficiency, they are usually very expensive machines, and require maximum utilization. By taking advantages of similarities of parts and grouping them into part families, Group Technology can help to improve the utilization of the machines and technologies [2, 20, 32, 58].

A survey conducted by CAM-I in 1975 shows a strong evidence of the importance of Group Technology in industry (Figure III.2). The survey indicated that Group Technology is one of the most important manufacturing technologies necessary to solve the current manufacturing problems [19].

Brief History of Group Technology: As previously noted, the first idea of Group Technology was introduced by Taylor in the early 1900's in the U.S. [33]. A Russian, S. P. Mitrofanov, was one of the first researchers to apply GT

CAM-I INDUSTRY SURVEY

(SUMMARY)

Japan	Europe	United States	Combined		Automotive	Electrical	Aerospace	Machine Tool	Research
PRIORITIES					PRIORITIES				
4	2	1	1	Mfg. Data Base Design	4	1	1	1	6
6	11	9	10	Computerized Mtrl. Handling	9	11	7	6	11
9	11	14	13	Comp. Controlled Transfer Ln.	1	12	12	14	12
3	9	13	12	Comp. Controlled Assy. Line Operations	8	9	11	10	10
10	7	8	8	In-Process Inspection	10	2	8	11	4
2	8	12	11	Die Sinking	3	8	10	13	9
7	6	2	4	Scheduling	11	3	5	3	7
4	3	10	5	N/C Verification System	11	7	4	7	1
1	7	11	7	Automated Drawing Generation	2	8	9	12	5
3	4	5	3	Interactive Graphics	6	1	3	8	2
5	1	4	2	Group Technology	5	6	1	5	3
11	12	6	9	Adaptive Control (A/C)	7	10	3	9	7
8	5	7	8	Direct Numerical Control (DNC)	13	4	2	4	3
12	10	3	6	Computerized Numerical Control	12	5	6	2	8

Figure III.2 Summary results of CAM-I Industrial Survey on Current Manufacturing Interests [19] concepts to the metal-working industry, and with the publication of his book "The Scientific Principles of Group Technology" in 1958 [49], a wide interest in the subject was made.

In Germany, some of the most important work in Group Technology was carried out at Aachen Technical University in the 1960's by Professor H. Opitz. Opitz developed a part classification and coding system for machined components, which is now one of the most popular classification and coding system in European industry [50, 51].

Professor J. L. Burbidge of the International Center for Advanced Technical and Vocational Training, Turin, Italy has done considerable work on Group Technology, and is most noted for his concept of Production Flow Analysis which provides a technique for forming machine-component groups in GT application [11, 12, 13, 14]. The Japanese also have been promoting the Group Technology concepts since 1960's for their higher manufacturing productivity [40].

Britain seems to be fairly well organized user of Group Technology. The Institution of Production Engineers formed the Group Technology section and a state-supported GT Center was established in 1968. A firm of industrial consultants, E.G. Brisch and Partners had developed an early interest in this area and have developed a classification and coding system which can be individually tailored for each user's need [39].

In the U.S., Group Technology has not received formal recognition and had not been rigorously practiced as a systematic scientific technology until the mid 1970's. However, the trend of intensified efforts on integrated computer-aided manufacturing has ignited wide interest in Group Technology.

3.1.2 Classification and Coding Systems

<u>General Concepts</u>: Classification is the process which arranges items into groups based on their similarities, whereas coding is the allocation of symbols to the groups previously defined. A more formal definition of the industrial classification can be stated as follows [39]:

> "Industrial classification is a technique for arranging the individual items comprising an aspect of a business in a logical and systematic hierarchy, whereby like things are brought together by virtue of their similarities and then separated by their essential differences."

Many of the industrial classification and coding system have been developed in different institutions. However, since each company has its own specific needs and considerations, it is necessary to search for a suitable system to meet company's objectives and requirements. Therefore, there is no universal classification and coding system to satisfy all of company's requirements. In fact, most of the commercially available schemes have the capabilities to be tailored to meet the specific needs and conditions of the users.

Classification and Coding Benefits: A well-designed classification and coding system provides many benefits and facilitates Group Technology in many areas of the company. The benefits of Classification and coding system in connection with Group Technology can be summarized as follows [32]:

a) Formation of part families and machine groups (cells).
b) Effective retrieval of design/drawings and process plans/routings.
c) Design rationalization and reduction of design costs.
d) Standardization of product design.
e) Secure reliable workpiece statistics.

f) Accurate estimation of machine tool requirement, rationalized machine loading and optimized capital expenditure.

g) Rationalization of tooling set-up and reduction of set-up time and overall production time.

h) Rationalization of tool design and reduction of time and cost for tool design and fabrication.

i) Standardization of process routings/toolings.

j) Rationalization of production planning and scheduling.

k) Accurate cost accounting and cost estimating.

l) Better utilization of machine tools, workholding devices, and manpower.

m) Improvement for NC programming, and effective use of machine and machine centers.

n) Establishment of a master data base.

From the information flow point of view, the volume of data flow in a typical manufacturing firm is very enormous. Dr. D. Allen has stated that classification and coding system can facilitate communications and reduce the necessity of special "translators" between various data base [6]. The benefits of classification and coding system in connection with information flow can be summarized as follows [6]:

a) Reduction of redundant data files.

b) Standardization of terminology.

c) Facilitation of information flow.

d) Increased overall efficiency of operation.

Basic Requirements for Classification and Coding: For Group Technology application, a classification and coding system should meet the following requirements [32].

a) All embracing:

A classification must embrace all the items being processed/purchased and be able to include all the future new item.

b) Mutually exclusive:

A classification must be mutually exclusive, i.e., like things are brought together while separated from unlike things.

c) Based on permanent characteristics:

A classification must be based on unchanged and consistent characteristics of the items, while those characteristics must be clearly defined.

d) Specific to user needs:

A classification must meet the specific objectives and requirements of the each user.

e) Adaptable to computer processing:

A classification can be done manually. However, it is strongly desirable to process it by a computer.

f) Adaptable to future changes:

A classification should be adaptable to future expansions and technological changes.

g) Company-wide applications:

A classification should be applied throughout all the departments within the company.

A classification should be based on one of the following concepts [52]:

a) Design oriented — where parts are classified and grouped together into families based on similarities of

	design features and/or overall shape (Figure III.3).
b) Production oriented	where parts are classified and grouped together into families based on identical or closely similar processes (Figure III.4).
c) Design and Production oriented	which is a compromise of both systems mentioned above to satisfy designers and production engineers with a single system.

<u>Types of Coding Systems</u>: There are basically three forms of classification and coding systems; namely

a) Hierarchical Structure (Monocode)
b) Chain-type Structure (Polycode)
c) Combined Structure (Hybridcode)

(a) Hierarchical Structure (Monocode)

One of the main features of a monocode structure is that

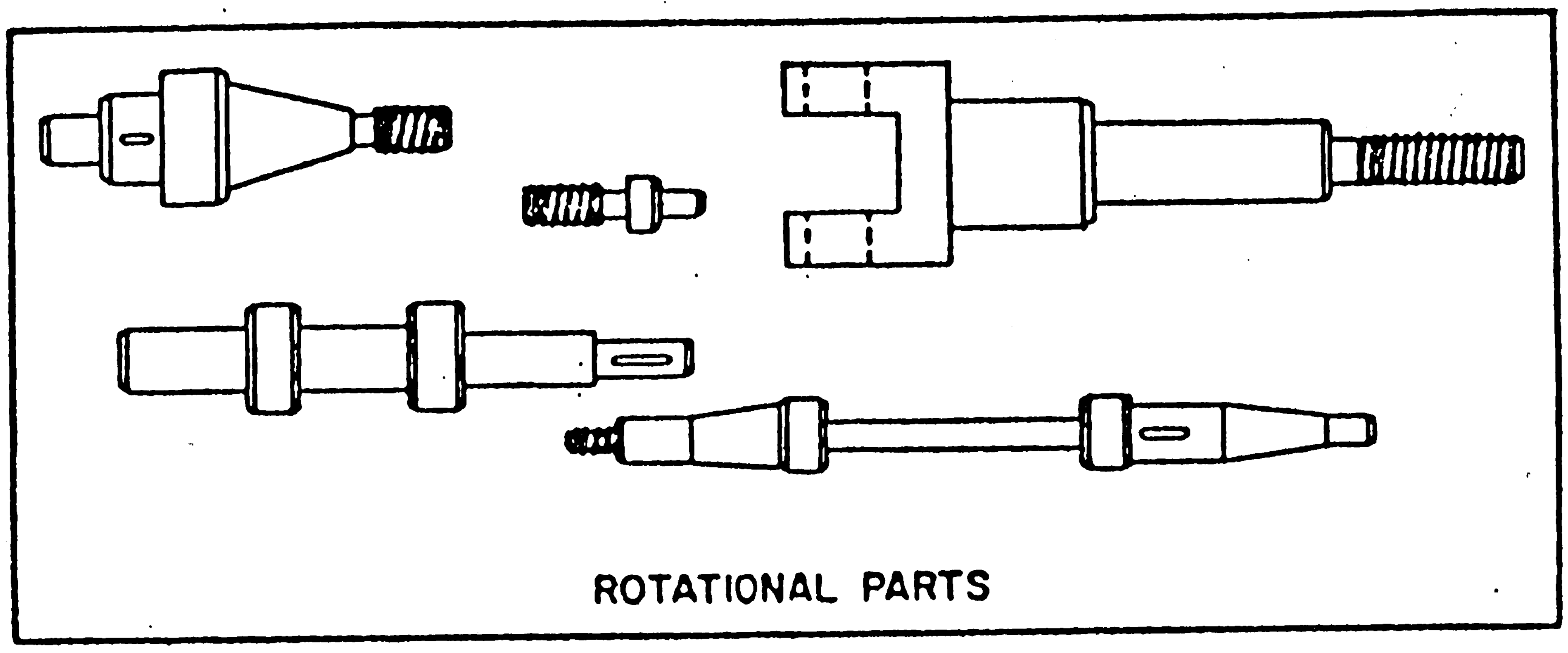


Figure III.3 (a) Rotational Parts

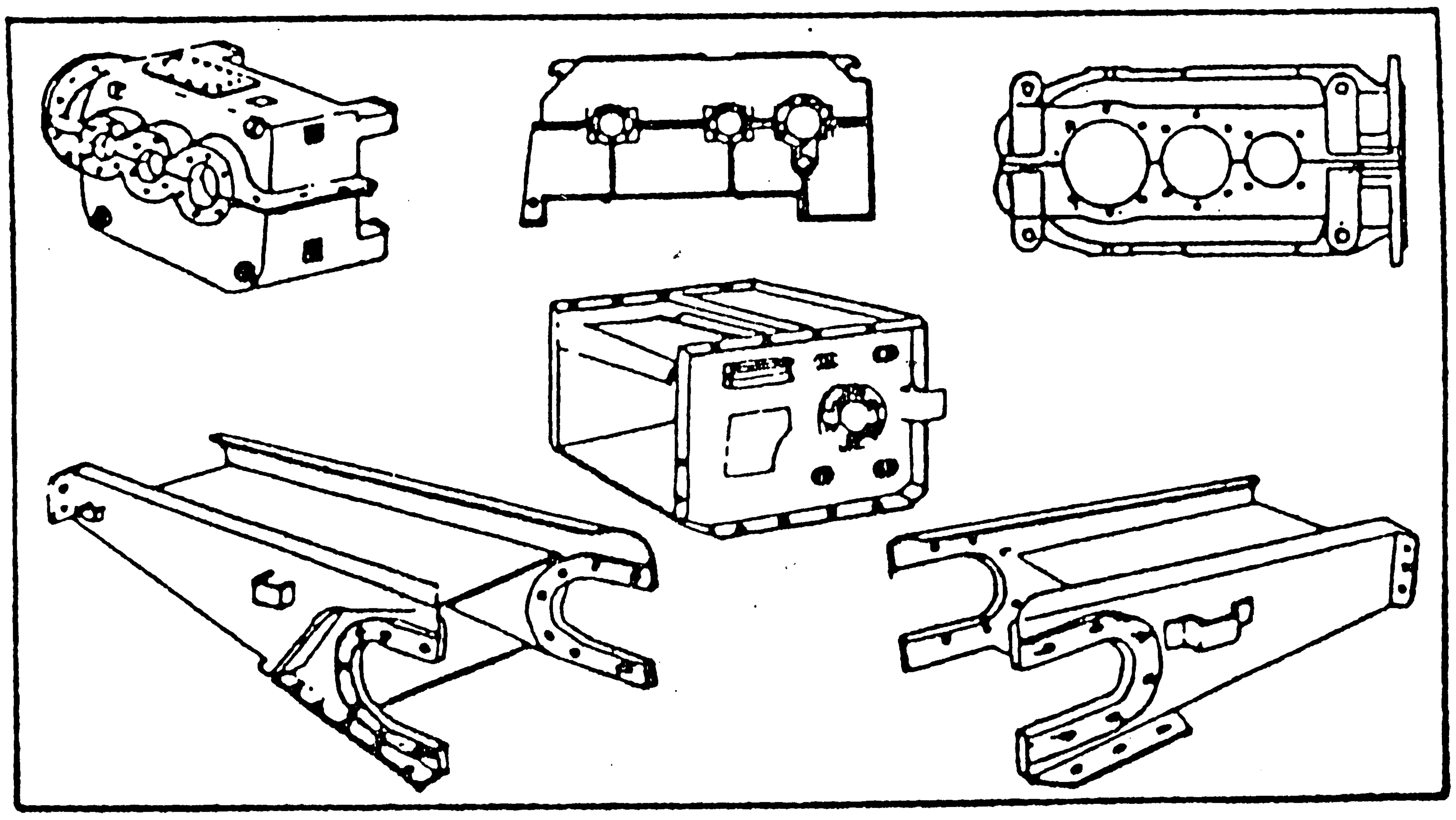


Figure III.3 (b) Non-Rotational Parts

Figure III.3 Design Oriented Part Families [52]

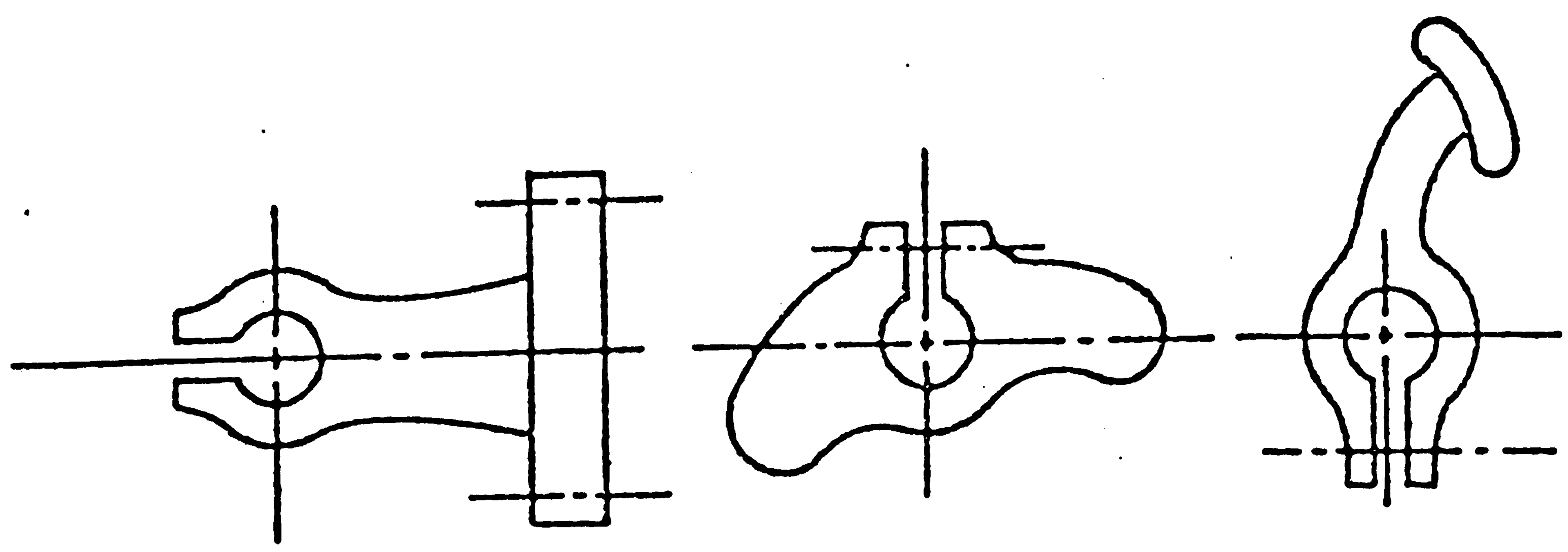


Figure III.4 Production Oriented Part Family
Sometimes parts can be grouped according to certain operations they need. These levers all require the same slitting operations. Grouped according to shape, they would never have found their way together. [52]

the meaning of every digit is dependent on the digits prior to it, which means that every digit is meaningful only after the prior digit has been defined. In other words, each element or digit amplifies the information given in the previous digit. Therefore, a Hierarchical structure may be represented as a tree structure. This type of structure is best for describing existing order structure (Figure III.5(a)).

For the development of a code structure, a few related distinctions that can be used to divide items into group of families should be established first, which makes it difficult to construct the Hierarchical code structure. However, once constructed, it provides a deep analysis of items classified and the resulting codes are very compact and contain a wealth of informations in a rather limited number of digits.

Because the grouping procedures of the this type of structure are typically design/shape oriented, a Hierarchical code structure has been used in design departments mainly for drawing retrieval purposes. Designers may easily traverse the tree structure and the family of parts of interest. From the manufacturing engineers' point of view, however, there are different requirements and a different code structure which reflects the manufacturing

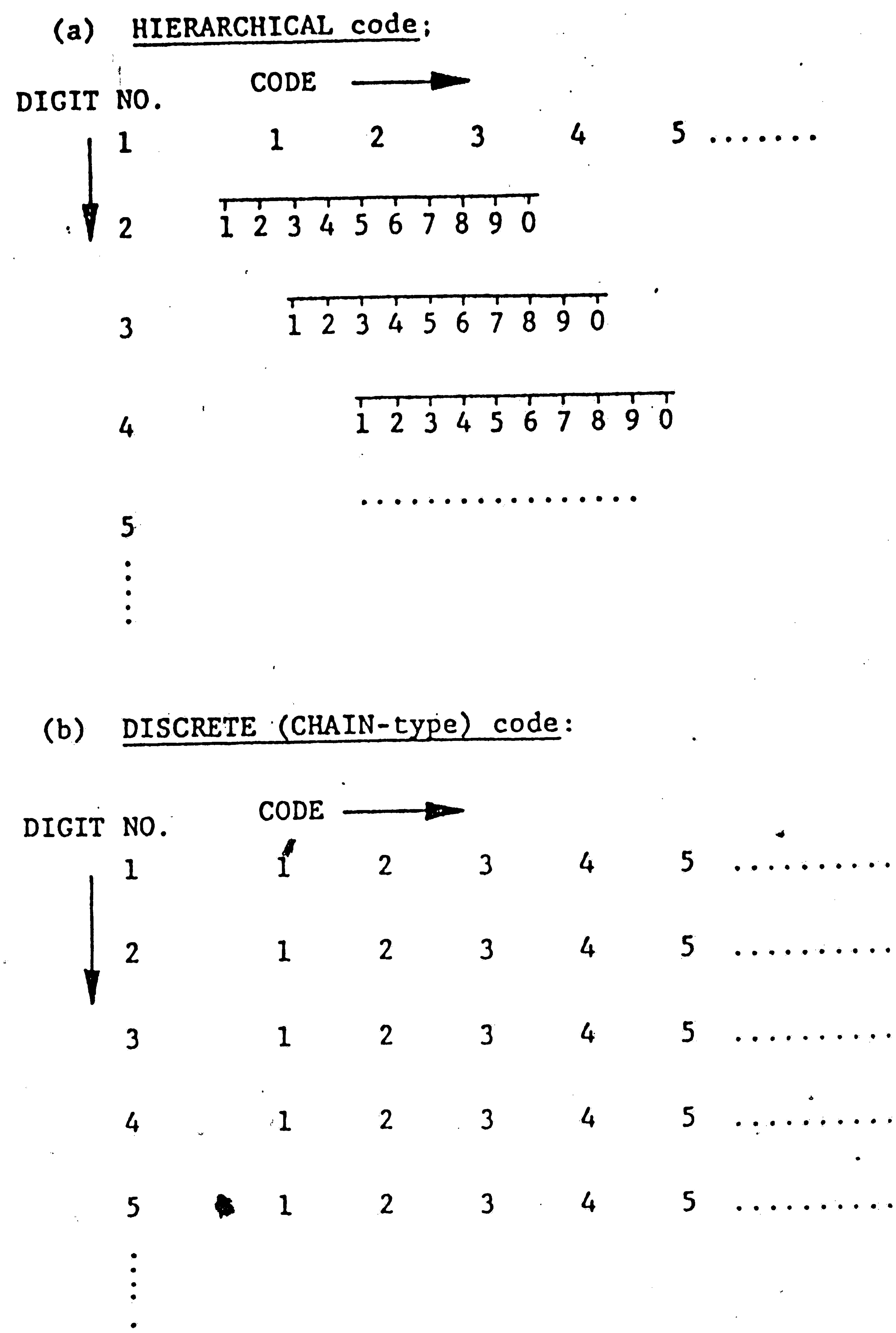


Figure III.5 Two basic types of coding structures: (a) Hierarchial and (b) Discrete (chain-type) [30] requirements is required rather than design or shape. Therefore, it is extremely difficult to develop a monocode structure for both designers and manufacturing engineers.

(b) Chain-type Structure (Polycode)

The main feature of this type of code structure is that the interpretation of each character in a given digit position is independent of any other digit, which means that each digit in the code represents the information in its own right and does not qualify the information provided other digits (Figure III.5(b)).

One advantage of the polycode structure over the monocode structure is that parts with specific characteristic can be easily identified. This feature makes the polycode structure attractive particularly to the manufacturing engineers for comparing parts in terms of their processing needs. In addition, a string of features associated with a part makes the polycode structure suitable to computer analysis.

One major problem with the polycode structure is that it tends to be overly long. To describe every conceivable feature of the population in detail, all associated digit locations must be reserved, even though many of the features do not apply to every part. A resulting code may easily run into dozens of digits.

(c) Combined Structure (Hybridcode)

This structure combines the best features of the monocode and the polycode structure and most of the industrial coding systems (e.g. OPITZ, CODE, KK-3, DCLASS) are categorized into this structure (Figure III.6). To reduce the length of the polycodes, the first couple of the digits split the population into several subgroups as in the monocode structure. And then, each subgroup has a polycode structure. Therefore, within each of these shorter polycodes, each digit is independent with each other. Such an arrangement makes the system helpful for the designers to easily figure out the characteristics of parts while it serves well to the manufacturing engineers in comparing parts in terms of their processing needs.

Code Structure and Format: Basically, there are three types of codes that can be developed for classification and coding system for Group Technology. These are (1) numeric codes, (2) alphabetic codes, and (3) alpha-numeric codes. Numeric codes have only 10 place values (0-9) while alphabetic codes have twenty six values (A-Z) which can be greatly extended with a use of upper/lower cases and

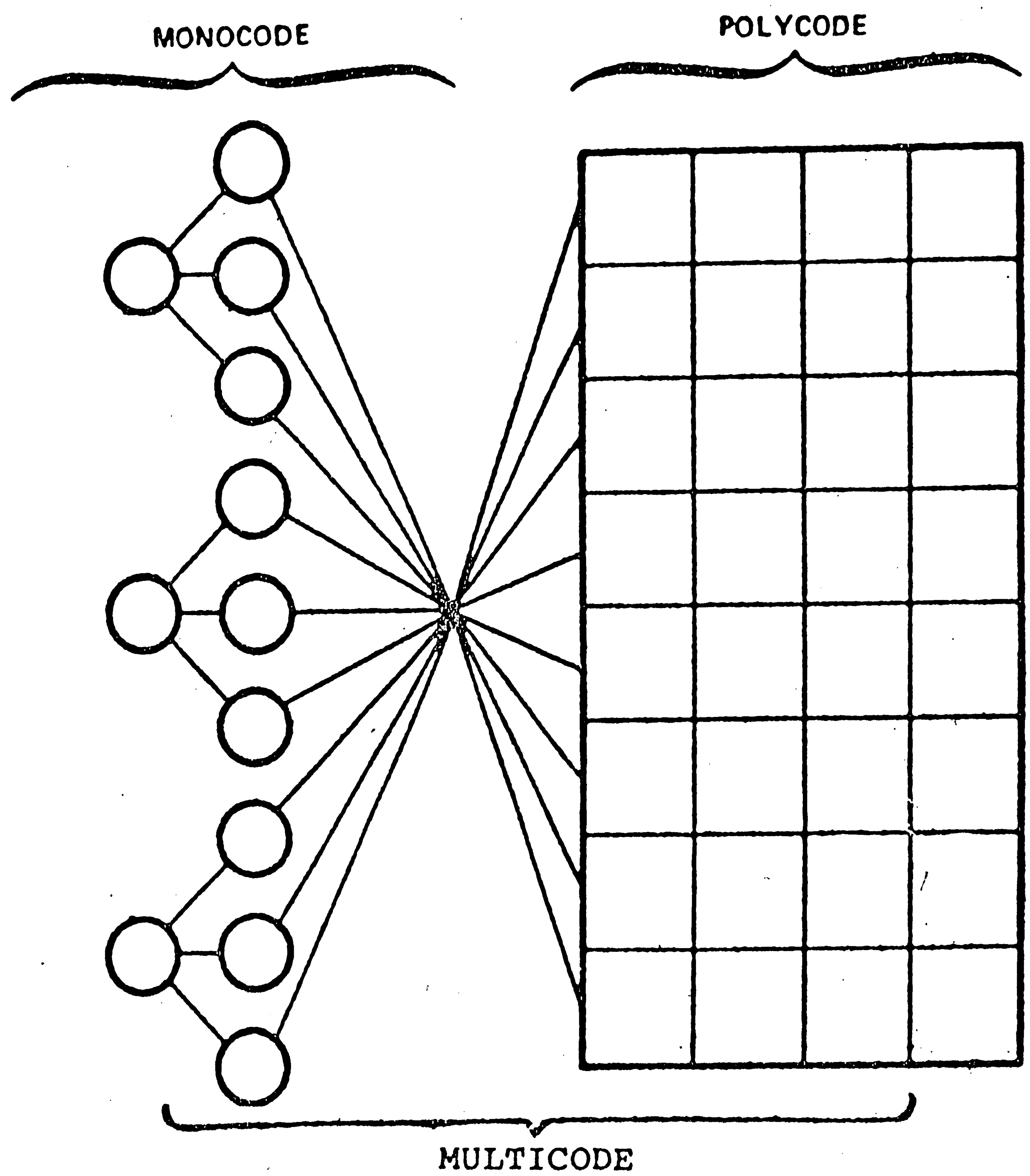


Figure III.6 Hybridcode Structure [30]

special symbols.

One of the important factors in developing classification and coding system is that it should maintain the balance between the amount of information needed and the number of digit columns required to code this information. The shorter the code is that still provides all the required information, the better it is in terms of retention, recording, and verifying. A series of connected short codes are compact and work efficiently. Several classification hierarchies may be linked together while providing pointers for the benefit of polycodes. As illustrated in figure III.7, each section of short code provides functional information separately, while the most detailed information is carried within the hierarchy of each short code if required.

In has been generally found that numeric codes are handled more rapidly with lesser errors, but at the same time have decreased recognizability and retentivity. Conversly, alphabetic codes have a greater error rate in use but have a longer retention time while keeping great recognizability. For both alpha and numeric codes, it is said that a code length of 5-7 characters will work well [6]. With longer codes, the error rate rises rapidly unless the codes are pronouncible(mnemonic) and meaningful.

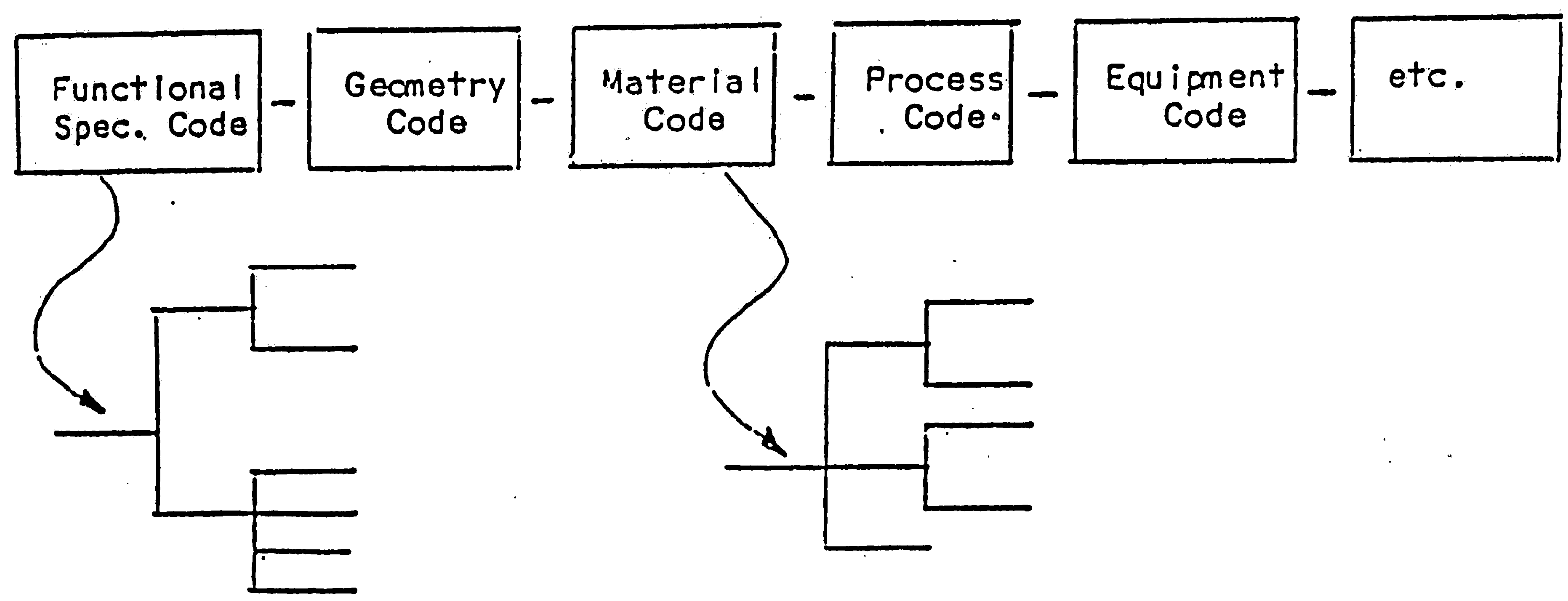


Figure III.7 Linking of codes [6]

Some general observations about code structures are stated as follows [6]:

(a) Digits are read faster with lesser errors than letters.

(b) Pronouncible codes have a lower error rate than meaningful codes, while meaningful codes have better recall value.

(c) There would be the greatest confusions in the alpha-numeric codes in dealing with some characters such as A-4, G-C, C-O, O-0, P-9, V-U, and Z-2.

(d) Recollection is improved in those cases, when alpha codes are arranged as words; then consonant-vowel-consonant common abbreviation; then non-sense syllables follows by digits then consonants.

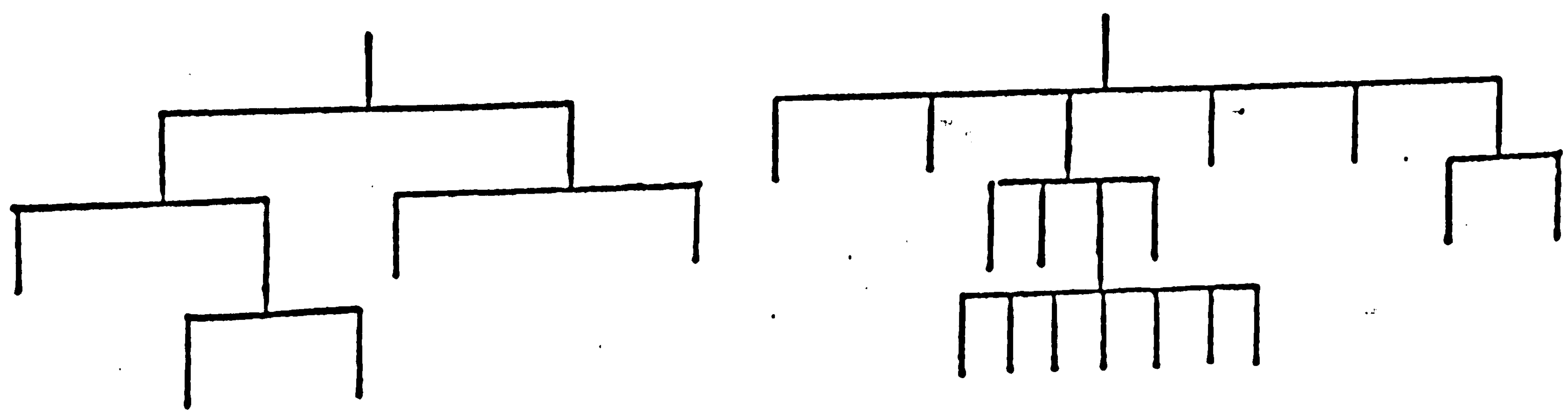
(e) Error rate rises rapidly when the number of letter are greater than 3 total per code word.

DCLASS system: DCLASS is an acronym for Decision Classification Information System. It is a general purpose information handling computer system for processing classification and decision-making logic. DCLASS is based on a tree representation. Each branch of the tree contains the information about characteristics of a part and its process required for classification. DCLASS processes this information tree under standard or user defined logic. There are basically three types of trees in terms of way they are processed.

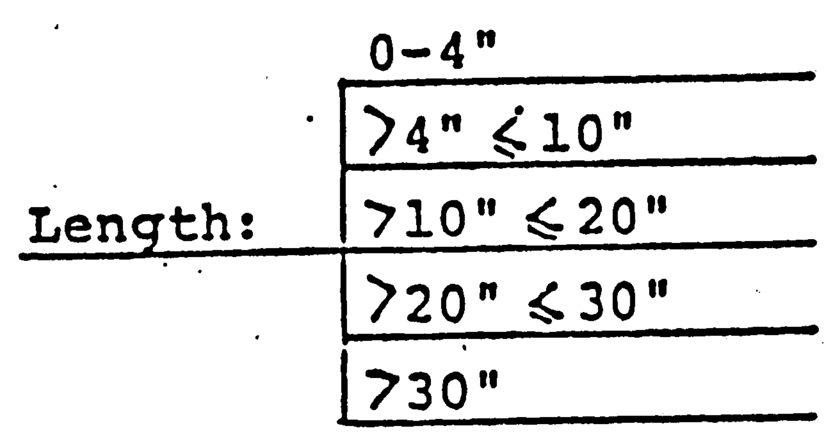
A mutually exclusive path tree (thus the name E-tree) allows the user to traverse one exclusive path throughout the tree (Figure III.8). Therefore, this type of tree is particularly useful for dividing a large population into small manageable groups.

Recent advances in computer logic permits the construction of two additional types of trees, the "N-tree"(Non-mutually exclusive path tree) and the "D-tree"(Decision value tree). The N-tree is one in which several or all paths through a tree can be traversed concurrently (Figure III.8). This means that many independent attributes for a subject may be selected concurrently without placing them in a hierarchical order.

The D-tree is somewhat different than either the E-tree of the N-tree in that value ranges are used rather than descriptive terminology. Therefore, the D-tree can be used to provide ranges of values and can also be used for automatic decision branching. E-tree, N-tree, and D-tree



Binary Tree   Poly-Tree



D-Tree for Part Size Range

Figure III.8 E, N-tree and D-tree [6]

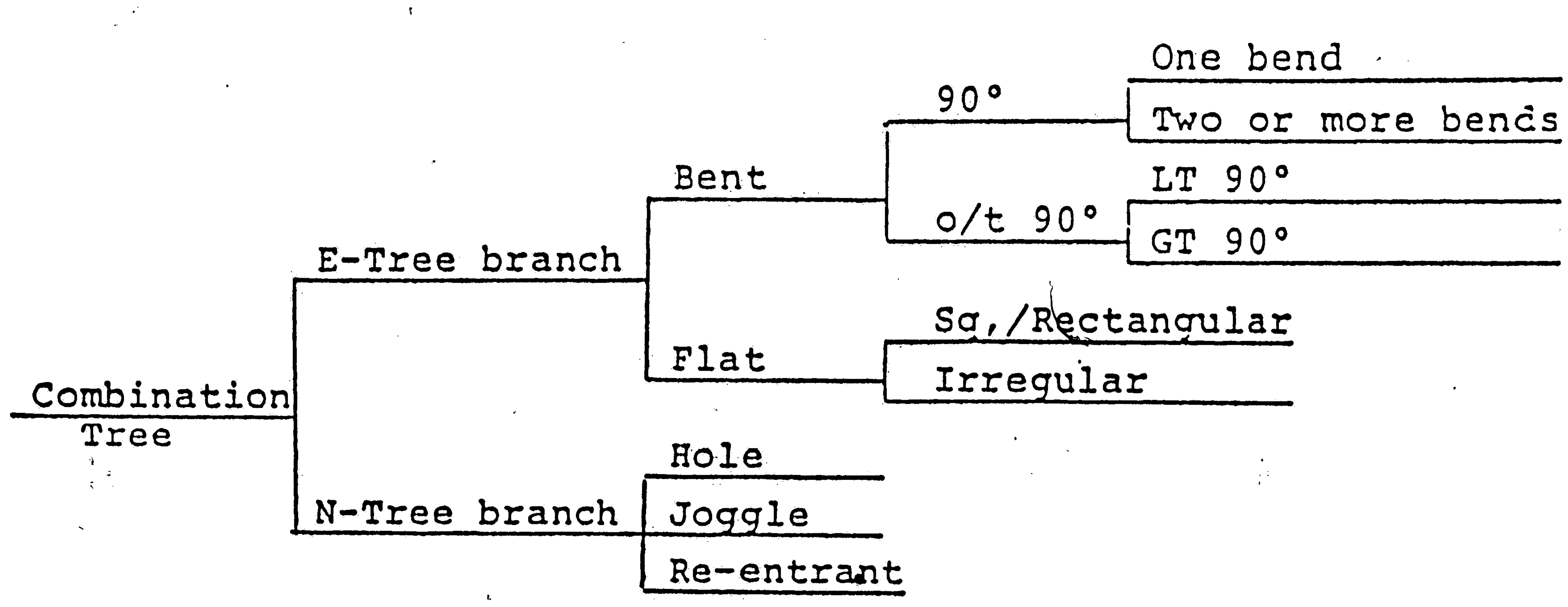


Figure III.9 Combined Tree [6]

may be used separated or in combination each other. In combination, they provide a very powerful, yet compact tree-structured system (Figure III.9). After traversing the above mentioned trees, DCLASS provides a string of code which contains information about design and/or process features of a part.

Compared with most of the commercially available systems, the DCLASS system has two distinctive features which make it very competitive. One distinctive feature is that DCLASS allows both standard and user defined logic. The DCLASS system can accommodate any known classification system. The logic behind many commercially available system can be converted to trees and used with the system. Once in a tree structure, the classification may be tailored to meet specific user's needs. This is an important feature because the needs for classification and coding are different from company to company.

DCLASS also captures the company's specific decision-making logic. Decision-making know-how is a key element of a company's business. DCLASS can analyze and capture the decision-making logic and technical knowledge base such that developed system may be easily and consistently used by others rather than experts in that field in the company. This is of advantage when developing an expert system for

Computer-Aided Process Planning.

The other distinctive feature of the DCLASS system is it's flexibility which allows easy interfacing with the user's own application program environment. Because most companies already have a variety of software, any system that is going to be installed should have a ability to interface with the company's existing system. In that sense, DCLASS provides a high degree of system integration within a company.

3.1.3 Production Flow Analysis

General Concepts: Production Flow Analysis (PFA) is a method for identifying part families and associated groupings of machine tools [13, 42]. PFA uses process route sheets to analyze the operation sequence and machine routing for parts produced in a given shop. The method groups parts with identical or similar routings together and the groups may then be used to form logical machine cells in a group technology layout.

PFA has particularly appeal in that it requires no special part classification and coding system, and is relatively simple to implement [26]. PFA forms part families which reflects process attributes rather than design attributes, and can be applied to the reorganization of existing, as well as the design of a new manufacturing system. Furthermore, from the classification and coding system developer's point of view, PFA provides increased learning opportunity about the process sequence and process attributes of the parts which he/she intends to classify and code.

Production flow analysis does have the weakness in that it uses the data which are derived from production route sheets. The process sequences from these route sheets have usually been prepared by different process planners, and these differences are reflected in the route sheets. The routings may contain process steps that are nonoptimal, illogical, and unnecessary. Consequently, the final machine groupings that result from the analysis may be suboptimal [26].

The PFA method involves a number of stages and may be described as follows [26, 41, 42]:

1. Classifying the machines. -- The first step in PFA procedure is to classify machines by a number according to type i.e., on the basis of the operation that can be performed. Machines capable of performing similar operations are usually classified with the

same type numbers. Machines required for minor and ancillary operations are excluded from the analysis, because experience in practice has shown that, unless such rationalization carried out, excessive distortion of the machine component groupings in stage 4 is likely to result [41]. Such ancillary machines are usually relatively inexpensive and can therefore be appropriately assigned to the required machine-component groups once these have been determined from the analysis.

2. Checking Process Routings. -- The second step is to extensively check the parts lists and production route sheets information in order to identify and ensure correctness of the essential information for the analysis.

3. Factory Flow Analysis. -- This step involves a macroexamination of the flow of components through the machines, which, in turn, allows the problem to be decomposed into a number of major machine-component groups.

4 Group Analysis. -- This is the most difficult and

the most crucial step in the procedure. The machine-component groupings are displayed on PFA charts and analyzed. Several methods for this step have been developed since the early 1970's [9, 13, 15, 16, 23, 41, 43, 45, 53, 54, 62] and one such method which is used in this research is discussed in the following section. The method is recently developed and relatively easy to understand and program for computation [41, 42, 43].

Rank Order Clustering (ROC) method: The data from the production route sheets may be represented by a machine-component matrix (PFA chart) in which cell entries for all values of i (rows) and j (columns) are X = 1 or X = 0 (more usually shown as a blank entry in the matrix). A cell entry of 1 indicates that component j requires an operation to be performed on machine i whereas a blank entry indicates that it does not (Fig. III.10).

The development of a PFA chart for machine-component group analysis may, in its simplest form, be expressed as that of determining, by a process of row and column exchanges of the matrix, a conversion from a haphazard pattern of entries into an arrangement whereby the 1 entries are contained in mutually exclusive groups arranged along

BINARY WEIGHTS →	2^5	2^4	2^3	2^2	2^1	2^0		
COMPONENTS	1	2	3	4	5	6	DECIMAL EQUIV.	RANK ORDER
MACHINES 01			1		1		10	5
02		1	1				24	4
03	1			1			36	2
04		1	1		1		26	3
05	1			1		1	37	1

Figure III.10 Initial Matrix [41]

BINARY WEIGHTS ↓	COMPONENTS	1	2	3	4	5	6
2^4	MACHINES 05	1			1		1
2^3	03	1			1		
2^2	04		1	1		1	
2^1	02		1	1			
2^0	01			1		1	
DECIMAL EQUIV.		24	6	7	24	15	16
RANK ORDER		1	5	4	2	6	3

Figure III.11 After Row Arrangement [41]

BINARY WEIGHTS ↓ →		2^5	2^4	2^3	2^2	2^1	2^0		
	COMPONENTS	1	4	6	3	2	5	DECIMAL EQUIV.	RANK ORDER
2^4	MACHINES 05	1	1	1				56	1
2^3	03	1	1					48	2
2^2	04				1	1	1	7	3
2^1	02				1	1		6	4
2^0	01				1		1	5	5
DECIMAL EQUIV.		24	24	16	7	6	5		
RANK ORDER		1	2	3	4	5	6		

Figure III.12 Final Matrix with Mutually Exclusive Groups [41] the diagonal of the matrix (Fig. III.12). The results correspond to machine groups (to be arranged physically in the form of group layout) and components into families (to be assigned to a specific machine group).

A Rank Order Clustering (ROC) method has been developed by King(1980) [41, 42, 43] for generating diagonalized groupings of the matrix entries. The ROC method uses binary weights to rank the rows and columns, respectively. This ROC algorithm can be described as follows.

(1) For each row of the machine-component matrix, read the cell entries and transform them to a binary weight. Calculate a decimal equivalence of each row's binary weight and rank them in order of decreasing value. Rows with the same value should arbitrarily be ranked in the same order in which they appear in the current matrix. For example, in Figure III.10 a binary weight of the first row is $2^3 + 2^1$, and its decimal equivalence is 10. The binary weights and their decimal equivalences of the next four rows determined in the same way as the first row. And the first row is ranked as the 5th.

(2) Re-form the machine-component matrix starting with the first row by rearranging the rows in decreasing rank order. Rank each colume in the same way as the rows previously described. For example, in figure III.11 a binary weight of the first colume is $2^4 + 2^3$ and its decimal equivalence is 24.

(3) Re-form the machine-component matrix starting with the first colume by rearranging the columes in decreasing rank order.

(4) Repeat step (1) through (4) until all of the both rows and columes are arranged in decreasing rank order and no further rearrangement can be made (Figure III.12).

It is assumed that the algorithm would normally begin with the original machine-component matrix but it is not necessary that it does. The procedure is iterative and it is possible to start with any rearranged form of the matrix.

The ROC algorithm rearranges rows and columns in an iterative manner and will ultimately end in a finite number of steps. The outcome is a matrix in which both columns and rows are arranged in order of decreasing value when read as binary words.

3.2 Computer-Aided Process Planning (CAPP)

3.2.1 Introduction to CAPP

Process Planning is the systematic determination of methods by which a product is to be manufactured economically. It determines the machining sequences, machining parameters, as well as other factors such as set-up times and run times based on the design features of the product and machine capabilities or capacities on the shop floor. Therefore, it has a function to link the information between engineering design and the shop floor. As Joe Tulkoff, the director of manufacturing technology at Lockheed-Georgia, has stated [64],

> "It(Process planning) derives it's input from the engineering side of the house as well as from the lots of data about the factory itself"

As such, process planning is a key factor in effecting the CAD/CAM link, and is one justification as to why the future trend of process planning is interactive computer-aided process planning.

Because of the important role of process planning between designing and manufacturing a product, the work of a process planner has considerably impact on the cost, quality, and the rate of production than any other activity in the company. Wrong process plans typically result in excessive scraps and/or reworks, low outputs, excessive in-process inventories, and, consequently, high production costs, while well-formulated process plans provide the desired quality and the required quantity on the planned schedule at minimal cost [28].

Although process plans play an important role in manufacturing products, conventional, manually prepared process plans have inherent problems. Such problems can be attributed to arising from inconsistencies and proliferation of different process routings.

The first problem inherent in the conventional process planning is based on the fact that manual process planning is a subjective activity which relies on the planner's previous experience, personal preference, extent of shop knowledge, interpretation of design requirements, and combined above. Therefore, ten different process planner would generate ten different process plans in manufacturing the same product. Obviously, all of these ten different process plans cannot reflect the most efficient manufacturing method, and furthermore, it is not even guaranteed that any one of them will continue to generate that efficient plan. Even more disturbing is that a process plan developed for a particular product might be different from the previous plan for the same or similar part [7, 64].

Gideon Halevi, director of the CAM/CAD R&D Center, IMI (Tel Aviv, Israel) studied features of process planning and concluded that manually generated process plans are highly dependent on the individual skill, human memory, reference manual, and above all, experience [28]. Resulting manually generated process plans are characterized as inaccurate, inconsistent, with, accordingly, high production costs.

In addition, process plans are not necessarily static. As lot sizes change, and new technologies, equipments and process methods are available, the most effective way of manufacturing the product should be changed, and reflected to the shop. However, the lack of uniformity and consistency in a manually prepared plan does not usually reflect all the progressive manufacturing technology changes. Therefore, there is a need for a logical, systematic method of process planning which can (1) capture the decision-making logic of process planning, (2) cope with today's dynamically changing manufacturing technologies, and (3) provide a good link between designing and manufacturing.

Computer-aided process planning(CAPP) attempts to rationalize the process routings and minimize the inaccuracy and inconsistency of a manual plan while obtaining the optimum plan of processes. The resulting optimum process plans from CAPP will provide the machining sequences, workcenter and machine codes, work content descriptions, and set-up and run times for each operation. The information required to determine the above factors in CAPP are usually facilitated by a GT coding system. In essense, CAPP extends the basic concept of GT in the sense that it takes information about like parts from the group data base and establishes the methods by which a product is to be manufactured. However, because more variables are associated with process plans than design, it is more difficult to develop the GT coding system which provides all the necessary information for CAPP. The resulting coding system often runs dozens of digits per item. Nevertheless, the success of CAPP depends largely on a GT coding system providing quality information.

3.2.2 Variant / Generative Process Planning

The traditional approach to process planning is to examine a part print and then identify similar parts from the planner's memory or from a code book. Once a planner identifies the same or similar parts, he manually retrieves the process plans for those parts and, if necessary, modifies the old plan to meet the special requirements of a new part print. If unable to find similar parts in the old files, the planner mostlikely would generate new process plans from scratch. While generating new plans or modifying old ones, he may consult with a foreman in the production shop to find out how the part is actually processed. To increase efficiency, a work book of process planning containing a menu of prestored sequence of operations for given types of workpieces is used.

The major advantages of the traditional approach is its low investment cost and flexibility. However, the lack of consistency in identifying and planning for similar parts, and the difficulty of updating a manual file to reflect new processes necessitates a logical and sophisticated method of process planning. In applying computer technologies to overcome the shortcomings of the traditional planning method, there are basically two approaches being developed, namely, the variant and generative approaches.

Variant Approach: The variant approach to CAPP is similar to the traditional approach except that computer assisted planning programs are required. This approach is based upon the retrieval of the standard manufacturing plans. Similar to process planning work books used in the traditional approach, standard manufacturing plans are first established for a particular part which has been classified through a GT classification and coding system and stored in the computer memory [64]. The computer's editing, high speed searching(retrieving) and printing capabilities are the major functions of this system. The planner can search and retrieve old process plan which is similar to what is required for the new part, and modify it to meet the new requirements. However, there is typically no logic available to aid in creating and maintaining the standard plans [64].

Before developing a variant process planning system, it is necessary to (1) develope a classification and coding system, (2) group the family of parts, and (3) generate standard process plans for each family group. Because the first two steps are the principles of GT, the concept of CAPP naturally has a basis in GT. As a result, a good classification and coding system and the rational determination of the standard process plans for each part family derived from the classification and coding system are indispensable for a successful CAPP system. The mechanism for developing a variant CAPP system is schematically shown in figure III.13.

Major disadvantages of the variant approach are 1) difficulty of constructing good/optimal standard plans, 2) difficulty of maintaining consistency in editing the plans

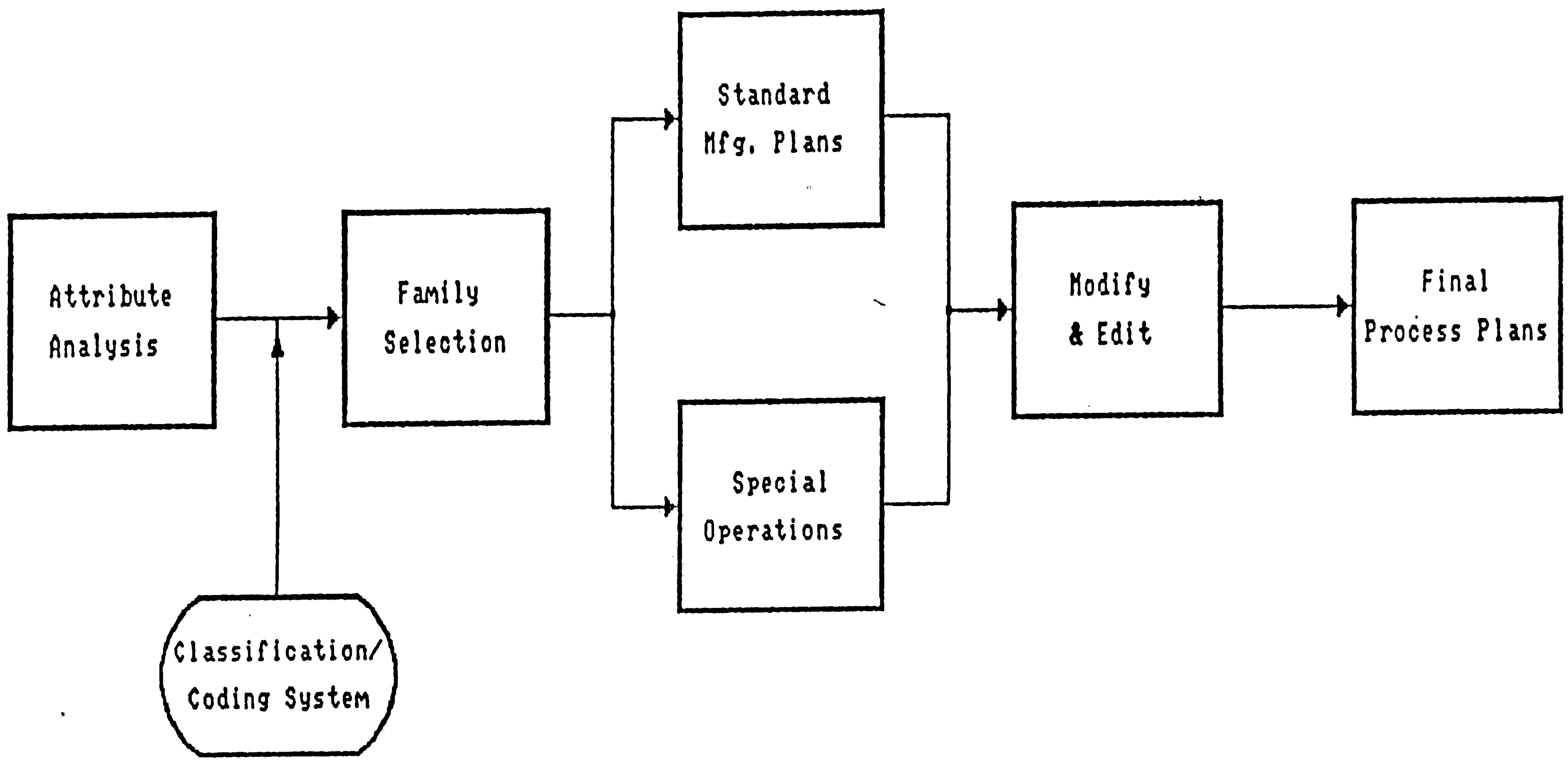


Figure III.13 Procedure of Developing Variant CAPP System (inflexibility), and 3) inability to adequately accommodate the various combinations of geometry, size, precision, material quality, and shop loading [8]. To minimize such shortcomings, it is feasible to apply the variant approach to the following conditions [7]:

1) The product design is fairly stable.
2) Lot size is medium-high.
3) Parts within a family are of similar size.
4) Material type is the same for all members of the family.
5) Few engineering changes are normally made.

Generative Approach: The major disadvantages of a variant CAPP system are the inconsistency of maintaining the plans and the difficulty of updating the plans to reflect the new technologies. To minimize the shortcomings of a variant CAPP system and to rapidly create a consistent, repetitive process plans which reflects new processes, methods, equipments, and toolings, a new approach, called generative, is being studied [7]. The generative approach generates process plans fully automatically based upon a series of pre-defined algorithms (e.g. decision logic, classification theory, mathematical models, formatting routines, etc.). A generative system should be able to construct an optimum processing sequence without reference to predetermined process plans. Such a system would draw upon (1) logical decision algorithms, (2) three-dimensional CAD part models and (3) a substantial manufacturing technology data base. Unfortunately, a general method for developing a generative system is not yet available [8]. It is thus extremely difficult to develop a truly generative CAPP system which automatically generates the sequences of operations as well as manufacturing parameters without reference to prior plans.

In developing a CAPP system one must consider that the decision logic varies from industry to industry, and from company to company. Therefore, it is necessary to develop a specialized system to suit a specific company's or operation's need.

3.2.3 CAPP using the DCLASS System

DCLASS(Decision Classification Information System) is a general purpose computer-compatible tree-handling system [5]. Because of it's capability of processing classification and capturing decision-making logic in a hierarchical information tree, the DCLASS system is compatible to a computer-aided and coding system based on Group

Technology. As noted earlier, the first two requirements of a generative CAPP system are the GT classification and coding system and the decision logic inherent in the process selection. Therefore, the generative CAPP system using DCLASS consists of two major function; (1) part information acquisition, and (2) decision tree traversal.

Part information required for process planning is collected by traversal of a general classification and coding system. Such information may include the basic shape, features, treatments, size, quantity, tolerance, critical dimensions, and material comprising part. In general, two different types of tree structures are developed for this purpose. One is the <u>part classification</u> tree structure, and the other one is the <u>material classification</u> tree structure. The collected information is then transferred to a process decision tree.

The decision tree traces an existing manufacturing facility's process capability, equipment, and planning strategies with the appropriate decision points set to detect particular information. Special features of a decision tree include the option of structuring the tree to properly sequence the output, the ability to easily modify the tree to accommodate new capabilities or capacities, the ability to detect the information from previous trees, and to use these information to choose a particular path.

The procedure of process planning using the above three types of trees (part classification, material classification, process decision logic) can be stated as follows:

(1) By classifying a particular part after traversing part and material classification tree, a information, codes, and variables require to traverse the decision tree are obtained.

(2) The collected information is transferred to the decision tree, which is then traversed automatically.

(3) After traversing the decision tree, a series of codes in a given sequence are obtained.

(4) The codes are then transferred to the text editor or report generator for an appropriate text and format for a process routing sheet.

The next chapter covers the nature of a case company and approaches to the knowledge base for above mentioned tree types of tree structures.

IV. Knowledge Acquisition from the Case Company

4.1 Nature of the Furniture Industry

4.1.1 Introduction to the Case Company

The case company studied as part of this research is a high volume furniture manufacturing company in the process of establishing a computer-integrated manufacturing (CIM) system. The company is placing particular emphasis on the production planning and control systems and the shop information system. As a foundation of the overall CIM system, the company's initial goal is to develop a group technology classification and coding system. The company's annual output is in the range of 200,000 finished products per year. Among the variety of products, their main product line is especially devoted to the executive office furnitures and the office working systems.

The executive office furniture consists of high-priced, single-piece furniture, such as desks, tables, or chairs, with a total sale contribution of 30 percent of the company's total sale. The office working system consists of modular furniture pieces. While some of the components of the modular pieces comprising a working cell are used throughout different cells and their basic structures are similar, many of the components are customized for the customer's specific needs and preference. For instance, worksurfaces having the same material, frame, and size may have different type of functional holes to satisfy the user's specific needs. These small options might result in huge proliferation of part designs and process plans. In actuality, about 50 percent of the products are manufactured based on specialized customer orders in the modular office furniture line.

The company currently has five different types of work shops, namely a woodshop, metal shop, fabric shop, finishing line and assembly line. Among the three shops making parts (the wood, metal and fabric shop), the wood shop is the most important in terms of the variety of the products, the volume, the price, etc. A five-layer ply panel and a three-layer ply panel are the major products of the wood shop.

Another consideration is that many of the company's products are designed by outside-company designers. Consequently, designation of the designer's name exist in the company's numbering system. Currently, there are four dominating outside designers with 60 percent of the total products carrying their signature.

4.1.2 Difference from the Metal-working Industry

In designing and developing a group technology classification and coding system in the furniture industry, one needs to consider what distinguishes the furniture industry from the metal-working industry. The characteristics which distinguish the furniture industry in terms of developing a classification and coding system can be summarized as follows:

(1) Assemble-oriented processes
(2) Hierarchy of assembled/subassembled parts
(3) Less variations in materials
(4) Simplicity in basic design
(5) Simple process parameters

The most noticeable difference between the furniture and metal-working industry is the way that a part is processed. In the metal-working industry, the most dominating machine processes involve metal-cutting operations, such as a drilling, cutting, or milling. In the furniture industry, the dominating operations are assembly operations which assembles raw materials together to form a component or part and again assemble components/parts to form subassemblies, etc. It rarely happens that one piece of raw material passes through the whole process line without being assembled with other parts. The nature of the operation resembles an assembly line rather than the traditional metal-working shop floor. In many cases, the term assembled "part" is more suitable and useful than "product" because it functions much more as a part in other forward assembly processes than as a final product. For instance, a five-ply wood panel is typically composed of several different raw materials or subassembled parts, and is still typically used as a part rather than a final product.

Because of the assembly-oriented nature of the furniture industry, a hierarchy of different levels of assembled parts becomes important in determining the information flow within the company. Special considerations, such as the level of a part in the assembly hierarchy, the function of a part at each level, the definition of terminology to define the hierarchical level of parts, and the various operations to make parts and assemble parts, should be made, and somehow reflected in a classification and coding system.

The next distinction between the furniture and metal working industries is the nature of the materials used, i.e. the metals and the non-metals, noticeably woods. Metals are available in large varieties and their properties are very sophisticated and complex. The choice of metal plays an important role in selecting the process parameters and tools. In the furniture industry, the dominating materials are woods. Wood properties do not have much influences on selecting the process parameters or tools. Less than ten different kinds of woods are dominantly used in the case company and discussions with company personnel indicated that wood selection has no bearing in selecting process parameters or tools.

Another characteristic in the furniture industry lies in the simplicity of their basic part designs. Even though there are substantial varieties in final products, about half of the final products manufactured are based on the customer's special orders in the case company. Basic designs are similar and common components are used throughout a different designer's products. This characteristic of the furniture industry can dramatically reduce the design attributes in developing a classification and coding system and allows more process attributes to be reflected in a limited number of digits of the classified codes for manufacturing.

Partially because of less variety of the basic design, process plans are not complicated and the logic can easily be captured with some exceptions (i.e. many of the operations are dependent on human decision and the logical procedure cannot easily be detected.). Typically, standard process plans can be easily generated for the basic parts and minor modifications such as location and number of holes can be made later when it is necessary to meet any special requirements. The characteristecs relevant to manufacturing in the case company are summarized as follows:

1) A basic product design is fairly stable.
2) Parts within a family are of similar size.
3) Woods are commonly used for all members of family.
4) Few engineering changes are normally made in basec product design.

This type of manufacturing environment seems especially suitable to applying variant type computer-aided process planning.

4.2. Analysis of Current System

4.2.1 Current Numbering System

To develop a GT based classification and coding system to contain the required information for all the departments throughout the case company, it is necessary to examine the company's currently existing numbering systems to see what codes are being used for which department, what information these numbered codes carry, and how these numbers are related to each other.

There are currently three types of numbering schemes being used in the case company, namely,

(1) Part number

(2) Conversion number

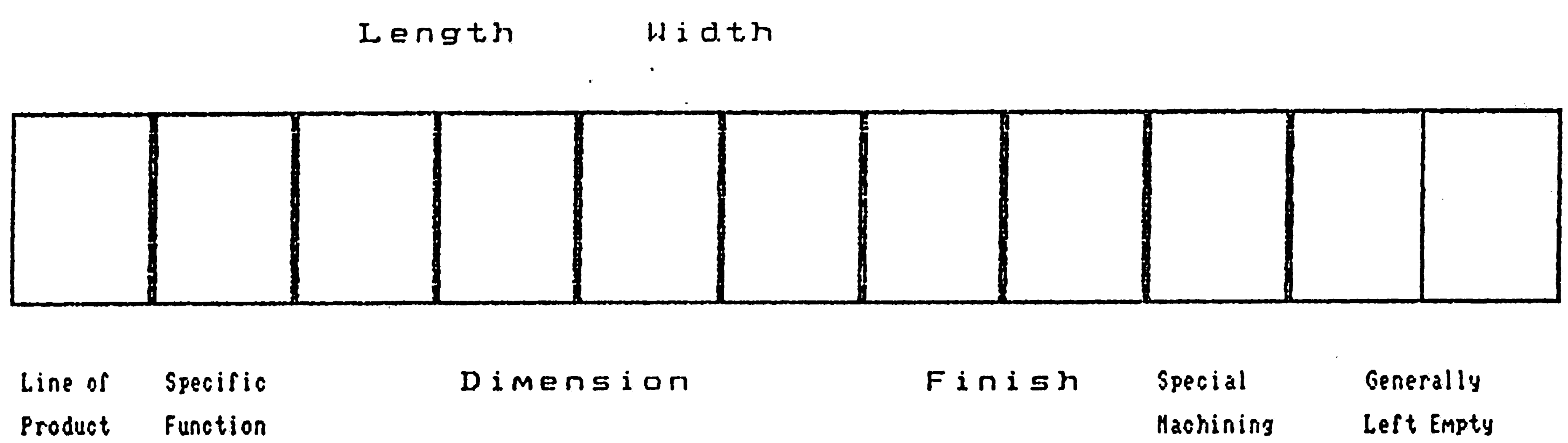
(3) Pattern number

These three different types of numbers have different functions on their own to meet the different departments' needs and are discussed in the following sections.

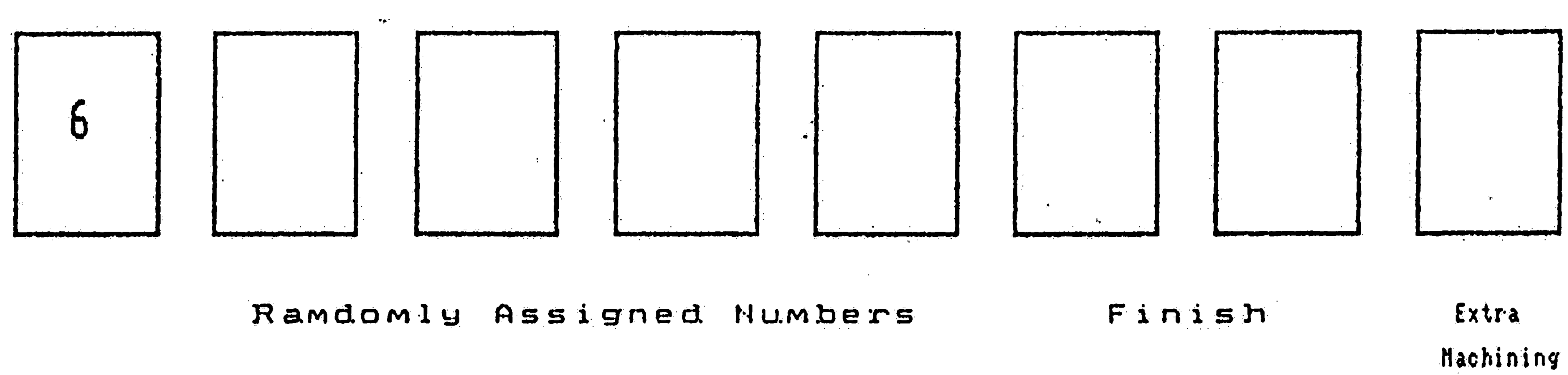
(1) <u>Part number</u>

This is probably the most important number used in the company in the sense that it identifies virtually all the parts(or components), subassemblies, semi-finished products, and sometimes, finished products. It's primary users are MRP, production control, the purchasing department, and the shop floor. The part number is created by the engineering database group. The part number is maintained in the Item Master File which contains a record (all the data elements, codes, and descriptive information used by the system) for each part, subassembly, and finished product for both standard or special products. The part number is thus the main key to the item master file. Most programs also use the part number to find a record. The part number represents all of the material flow throughout the plant and is widely used throughout the company.

According to the company's published document, entitled "Item Master Maintenance Task", a part number is described as an eleven character unique identifier. In actuality, however, the eleven character rule is never observed, and the length of number varies from two digits to eleven digits. Furthermore, there is no consistency in assigning a digit to a particular position of the number. In other words, a particular position in the number may or may not be meaningful. A meaningful part number in which a particular position is meaningful may have the following structure:



Concurrently, a meaningless part number could have the following structure:



* The first digit, 6, indicates that the consequent four positions are meaningless.

The case company especially stresses the importance of the two digits of a finishing code. These digits are used to define the finish to be applied, to sort shop order reports for the finishing departments, and to schedule the finishing department. Of note is that the company refers the designer's name to the line of the product (first digit), partially because over 60 percent of the total products designed are marketed with the designer's name.

As mentioned earlier, about half of the products are manufactured on a special order basis. Whenever a special product is a variation of a standard product, a new part number is assigned to the special product. This special part number begins with the equivalent standard number and end with a "Q" suffix which uniquely identifies the product. This procedure is done by the Sales Estimating Department as part of the quotation request process.

Even though the above structures are recommended company conventions, in many cases it is found that many of the part numbers do not strictly follow the recommended structures.

(2) Conversion number

The conversion number is a six digit number which is used to classify the product and associated parts into families and sub-families for both marketing purposes and manufacturing planning purposes. This is a dependent numbering system (monocode structure) with significance in each position depending on the contents of earlier positions.

The whole six digit number can be divided into two sub-set of numbers. The first four digits are grouped together as a family number to organize the products into the specific product line. This is a rigid convention of the company and generally proposed by the marketing department for the purpose of general accounting and royalty payments. The last two digits are grouped together as a sub-family number which is rather arbitrary and the definition of each digit is dependent on a particular product line. The more detailed and illustrative numbering scheme is as follows:

- all six positions = conversion number
- 1st four positions = family group
- 5th and 6th positions = sub-family group
- first position contents and meaning
  1 standard furniture (domestic)
  2 special furniture (domestic)
  3 standard textile

4 standard furniture (import)

5 not used

6 special furniture (import)

7 special textiles

8 not used

9 groups of common use purchased material

0 not elsewhere classified

- 2nd position contents meaning for furniture

1 seating

2 credenza

3 bedroom

4 tables

5 desks

6 systems

7 not used

8 not used

9 accessories

0 not elsewhere classified

- 3rd and 4th position = designer/design group
- 5th and 6th position further refine categories depending on type of furniture, e.g. tilt swivel chairs, side chairs, etc.

A conversion number has more strict rules than a part number, and these rules imply the concepts of a GT classification and coding system.

The primary user of the conversion number is the Master Production Scheduling (MPS) group. The main documents to use the conversion number are the Master Scheduling reports and the Predicted Annual Sales reports.

(3) Pattern number

A pattern number (sometimes referred to as an "order number") is the number which identifies the final product ready for sale. It is the number which appears in the product catalogues or price lists and is imposed by the marketing department. Because part numbers for the finished products are also called pattern numbers, there is confusion in distinguishing those two numbers. For instance, in the case company, a five-layer ply panel is one of the major parts to manufacture while it is also sold as a final product. The main difference between the two numbers is the condition of the object to be assigned in terms of processing. The pattern numbers are assigned to the final products, while the part numbers are assigned to the unfinished products, such as components, subassemblies, or semi-finished products.

The number series of a pattern number generally do not include the unique part numbers for every option. Frequently, product options are specified in words selected from a list printed in the catalog/price list. These options are to be converted into the suffix codes which are included in the part number.

We have discussed the three different types of numbering schemes which are currently being used in the case company. These three types of numbers have different functions and are used for the different departments of the company. The diagram in figure IV.1 is helpful to understand how these three numbers are related to each other in terms of the department usage.

The three different types of numbering schemes currently being used present shortcomings which are summarized as follows:

(1) Inconsistency in assigning a number

(2) Confusion in use

The first shortcoming applies especially to part numbers or pattern numbers. Part numbers are usually generated by the company's convention. The company suggests the recommended

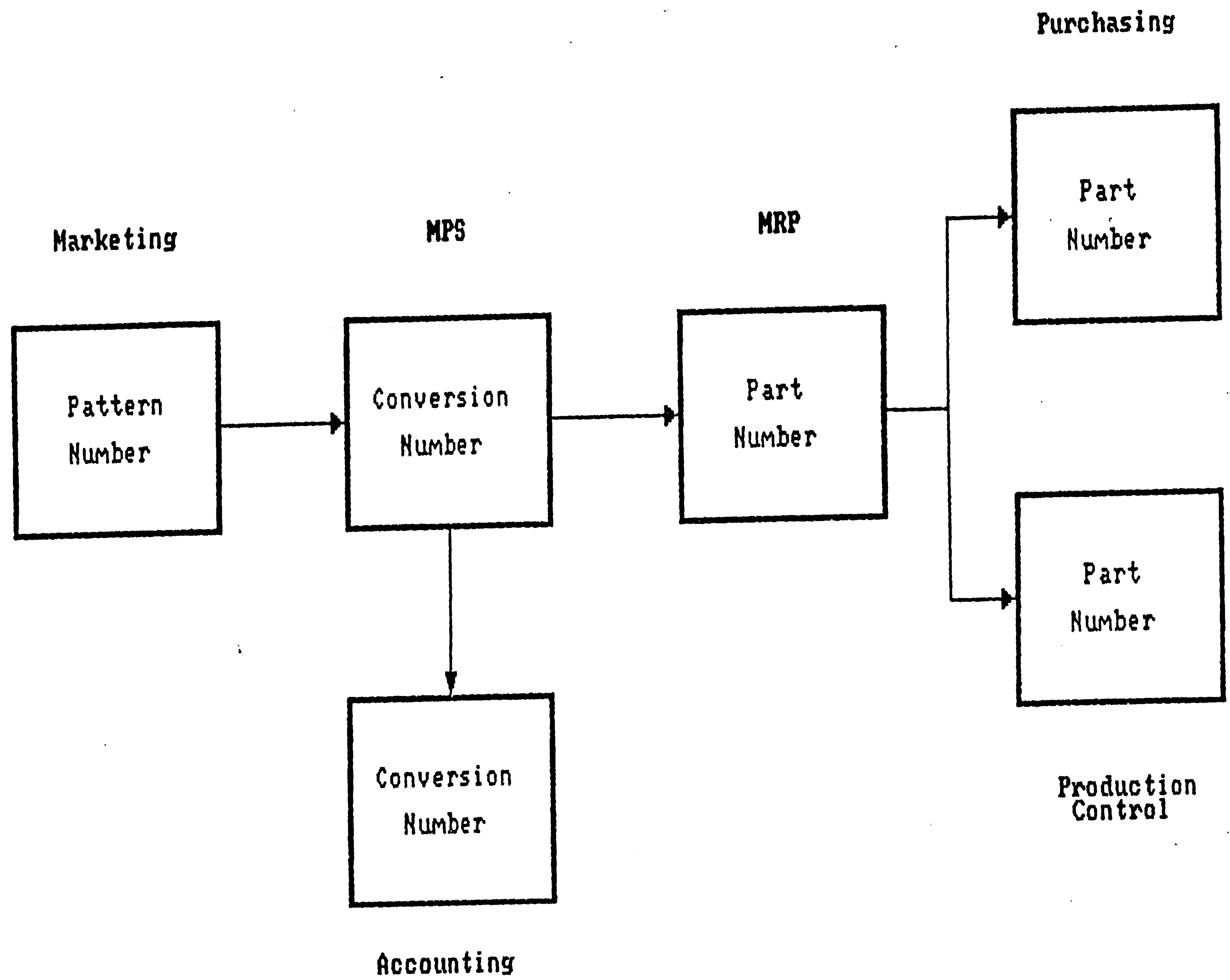


Figure IV.1 Multi-Mumbering System for Different Department usage structure of the part number. However, the problem is that the suggested form has been rarely followed. The following randomly selected part numbers from the case company might be helpful to understand the inconsistency of part numbers.

GMT4318C8 is a part number of a standard top panel, where the G, MT, 4318, C8 identify the product line(designer's name), function(standard top), dimension in inches (43x18), and surface finish, respectively. And EBZ72C4 is a part number of a edgeband of the Zapf system, where EB, Z,72, C4 identify the function(edgeband), product line (designer's system), dimension(length), and finish, respectively. As can be seen, there is no consistency in two part numbers in terms of their length(9 digits vs. 7 digits), meaning of position of digits, etc. Furthermore, the part number of a veneer, 8067070, does not say anything in itself. Even though the company suggests the special part identifier - Q - to be added to the end of a standard part number as a suffix, the Q actually appears in any position of the part number string. Therefore, it is very difficult for the inexperienced person to visualize the part by its part number. Even an experienced employee is easily confused to identify the part he is dealing with.

Another major shortcoming of the current numbering system comes from the fact that three different types of numbers are used within the company. These three numbers are generated by different departments for different purposes. However, the problem is that two different (sometimes three different) numbers can be assigned to the same part. The people of the master production scheduling group(MPS) may use a conversion number while the foreman uses a part number. This multi-numbering system for the same part can be an obstacle to unify the information flow of the company. Therefore, there is a need to develop a new numbering system which can be universally used through the different functional departments.

4.2.2 Current Engineering Routings

The case company currently uses a electronic filing system, which is called the Engineering Routing File, to create and maintain the existing process plans by the engineering department. The engineering routing file contains one record for each manufacturing part, assembly, or finished product. One of the data elements included in the record is each manufacturing operation which is to be completed to make the part. Other data elements of the engineering routing record are listed as follows:

- <u>operation-sequence number</u> which identifies the sequence in which the operation is performed.

- work-center number which identifies the work center in which the operation is performed.
- operation-description which describes the operation.
- setup-time which defines the time required to prepare the machine or work center for this operation.
- run-time which defines the time required to perform this operation for one piece.
- run-code which identifies the type of routing data included in this record, that is, E(estimated) or S(time study).
- number of people required to perform this operation.

Engineering routings are created and changed by using computer terminal programs. The following files/documents are often referred in creating and changing the engineering routings:

(1) Item master file

This is also an electronic file which contains one record for each part, subassembly and finished product. The record includes all of the data elements, codes and descriptive information used by the system.

(2) Machine list

This list contains all the machines in machine number order, the supervisor, and descriptions of each machine. The description is, however, only the name of a machine and does not describe the basic functions of the machine. An inexperienced person might have difficulties in determining the function of the machine and its applications.

(3) Machine restriction file of the woodshop

This list shows the allowed part dimensions which can pass through a particular wood fabrication machine.

(4) Timesaver file

This file identifies the time consumed in a particular machine center for each of the different dimensions of a particular part. The process planner utilizes this file to find out the machine which consumes least time for a particular processing for a particular part.

The above files/documents do not provide the full-depth of information required for process planning. A process planner often refers to his own notes or experience, or, in many cases, it is necessary to go to the shop floor and ask a supervisor or foreman about what he needs to know.

Generation of process plans for the case company's products has been quite conventional. Process plans are manually generated by a planner and are mainly based on his/her previous experience and knowledge about the shop floor.

There is no standard process plans/procedures prepared for a part - even the mostly widely used popular part. When a blueprint of a new part is released, a process planner first examines a blue print and then, identifies similar parts mainly from his/her memory or code book. Once he/she determines a same or similar part, he/she manually retrieves the old process plan and modifies it if necessary. If the process planner does not find similar parts, the process plan is generated from scratch. Since there are no logical procedures in the company, the resulting process plan will be based on his/her own knowledge and experience and may be not be an optimized plan.

Unfortunately, only a few people in the product engineering group of the case company are considered very knowledgeable about the information required for process plans. The lack of logical procedures established for process planning through well published documents presents a situation where many of the less experienced planners tend to refer to key people about the information they need. When a key person resigns his position, there is no mechnism to keep the information within the company.

4.2.3 Statement of the Problem

The objective of this research is to develop a numbering scheme based on the concept of group technology. The new GT-based numbering system should encompass the following areas:

(1) Designing/retrieval of the part drawing
(2) Shop floor control
(3) Machine scheduling
(4) Consistent production reporting
(5) Process Planning and Future CAPP

The critical point in developing a new GT-based numbering system(classification and coding system) lies in the integration of the design aspects with manufacturing aspects within one coding scheme. Since each department has its own functions and purposes, the information required to be reflected on a coding system would be different from department to department. However, it is very difficult to pack an enormous amount of information into a limited number digit code. A subobjective of the research is to then determine the subset of information which is reflected on the new coding system for the benefit of each department.

4.2.4 Approach to the Problem

As a result of discussions with the case company, a recommended GT-based classification and coding system should meet the following conditions:

(1) Universally applicable to all the departments

(2) Serve as a front-end to a Computer Aided Process Planning system

To facilitate this effort, it is necessary to link process related departments with design related departments. In other words, the classification and coding system should contain both design and process features of a part to be commonly used in these two different functional areas and link them effectively. Because process planning is located at the crossroads of information between engineering design and the shop floor, CAPP is a key factor effecting the CAD/CAM link. A properly developed classification and coding system should carry enough information about a process to serve as a front-end for a CAPP system.

To collect the required information from various sources in developing a classification and coding system, a framework is developed and shown in figure IV.2. There are basically two processes which have to be done separately to collect the required information - the design related and process related information. Interviewing the people in the field is the first step in both areas and provides a broad knowledge about the field area. In the process of design related knowledge acquisition, blueprints of a part and the related documents are examined, and the information about a product line, functional hierarchy dimensions, and materials are collected. A route sheet analysis and a production flow analysis are done to find out process related knowledge such as standard/special machining processes and bottle neck machines. After collecting the information on both design and process features, this knowledge is combined to form a new classification and coding system.

4.3 Approach to the Knowledge Base

The approach to the new classification and coding system is to have four different functional short codes which are connected together to form a complete code. The functions of these short codes and their main sources of information are demonstrated schematically in figure IV.3.

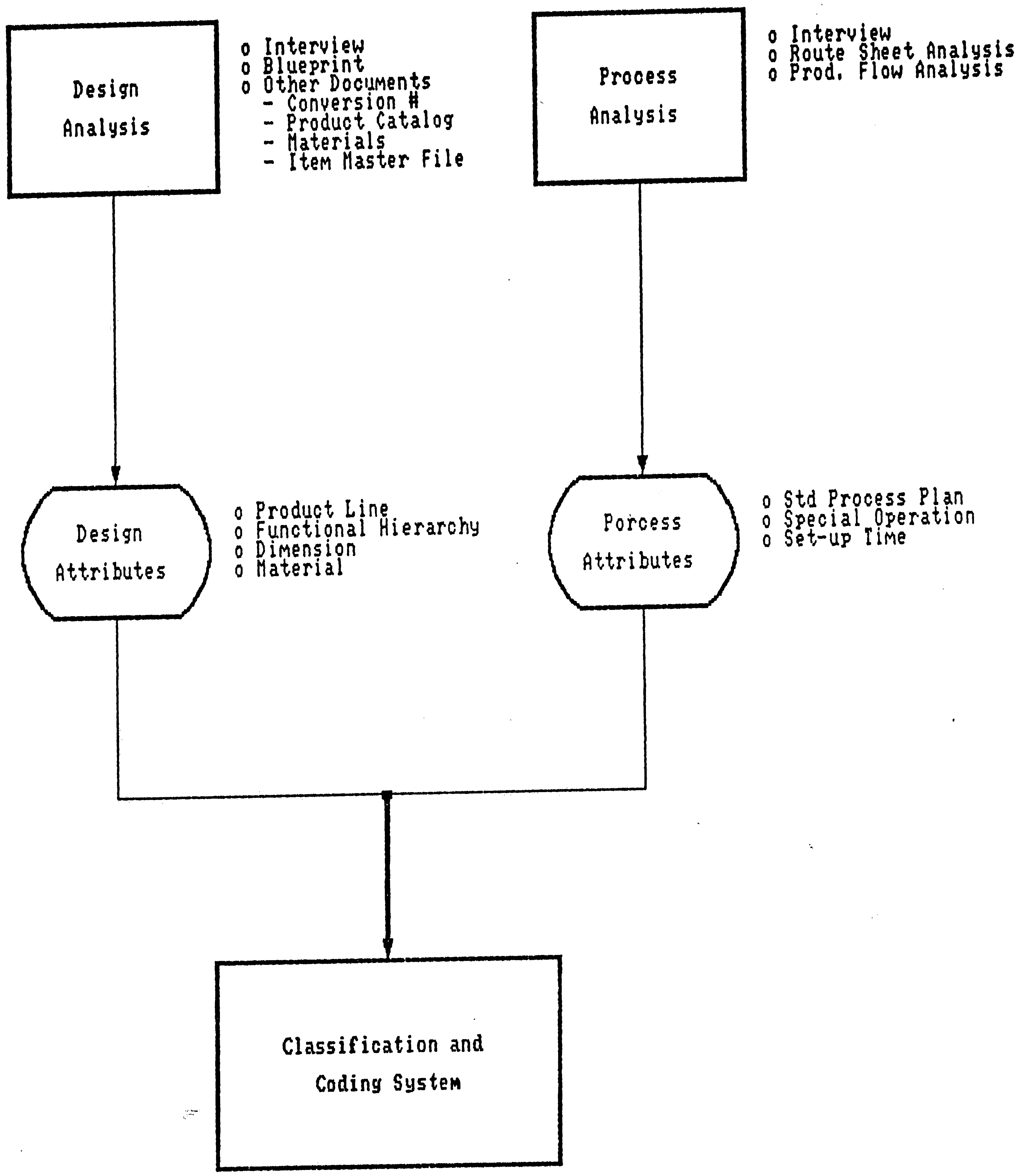


Figure IV.2 Collecting Information about Design and Process Aspects

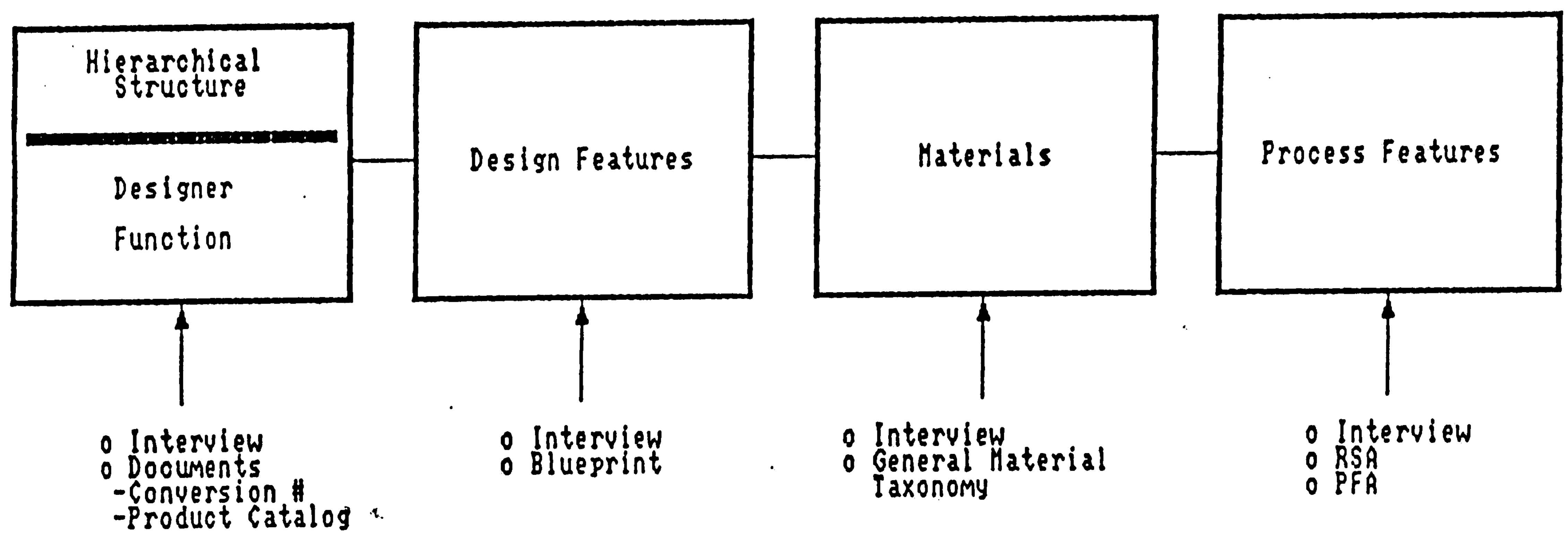


Figure IV.3 Functional Parts of Code and Sources of Information

4.3.1 Analysis of the Design Features

As a first step in obtaining a knowledge base, the design aspect of a part/product is analyzed. A product line of a case company and their hierarchical groupings are first discussed and a structure of the most widely used part - 5 ply panel - is analyzed. Characteristics pertaining to the dimensions of a part, materials used, and their finished color are analyzed and discussed in the following sections.

<u>Product line</u>

Products manufactured at the case furniture company can be divided into two groups: systems and individual furniture. A system is a group of different functional furniture. The system can have different configurations by different arrangement of different functional furniture. This system furniture accounted for 62.5 percent of total production in 1985. There are currently five outside-company designers who design the system furniture. The product line is identified by carrying the designer's name with the product. A designation of the designer's name appears in the company's currently numbering system. Among five designer's systems, the four systems - Morrison, Zapf, Hannah, and Stephens - accounted for 98.7 percent of the designer's system in

1985. Oar constituted only 1.3 percent.

Individual furniture accounted for 37.5 percent of the total product in 1985. There are six functional sub-groups in the individual furniture group. Office seating is the major group which accounted for 51.2 percent of the individual group in 1985 and the proportion seems to be increased in this fiscal year. The other sub-groups consist of side chairs, multiple seating, desk & credenzas, lounge seating, and tables.

Production Level (Hierachical Analysis)

Because of the assembly-oriented nature of a case company's products and process, it is important to define a hierarchical level of products and/or parts to facilitate information flows.

By analyzing material flows in a shop floor, it is found that five production levels can be defined in describing the hierarchy of the products and/or parts in the case company: grouping, assembly, subassembly, component, and raw material.

1. Grouping - A designer's system can be included in the top level of hierarchy. This level will be particularly useful for the sales person in identifying

the designer's particular system.

2. Assembly - A piece of furniture of a designer's system or individual furniture. This level will also serve as a reference code in a price list or a product catalog to help marketing people. Assemblies and groupings are ready for sale.

3. Subassembly - This is probably the most crucial level of the hierarchy from the production(or shop floor) point of view. This level corresponds to parts which are assembled/arranged to form a assembly/grouping. They also can be sold themselves. Subassemblies differ from components in that they can be directly assembled to form a assembly and/or sold by themselves as a final product.

4. Component - Components are the parts which are put together to form a subassembly. The component differs from raw material in that the component is ready to be assembled to form a subassembly while raw material requires processing to be directly used for subassembly. For example, a frame is a component while a wood rail for frame is a raw material. In the same way, inserts and nuts are considered as components because they can be directly used without any machine processing.

5. Raw material - This is the lowest level of hierarchy. None or very basic machining process are done at this level.

Structure of the Parts/Components

Among the various components used in manufacturing furniture at the case company, a 5-layer and 3-layer ply panel are the most widely used components or parts. They are used in virtually every piece of wood furniture. The 5-layer and 3-layer ply panels were chosen as the starting points for analysis. Since the 5-layer ply panels require more process operations than the 3-layer ply panels, the 5-layer panel is analyzed initially.

A 5-layer ply panel is primarily used as a worksurface. Variations in manufacturing the panel arise primarily from the condition of the holes. The holes vary in number, locations, and types. The structure of the panel is relatively simple and the makeup of a typical panel is shown in figure IV.4.

A 5-layer ply panel is basically composed of four different components - frame, MDF, veneer and edgeband. The core of the panel is a frame which is inserted with a verticel. The verticel is a technical name of a board stuffing resembling a honeycomb. The verticel aids in

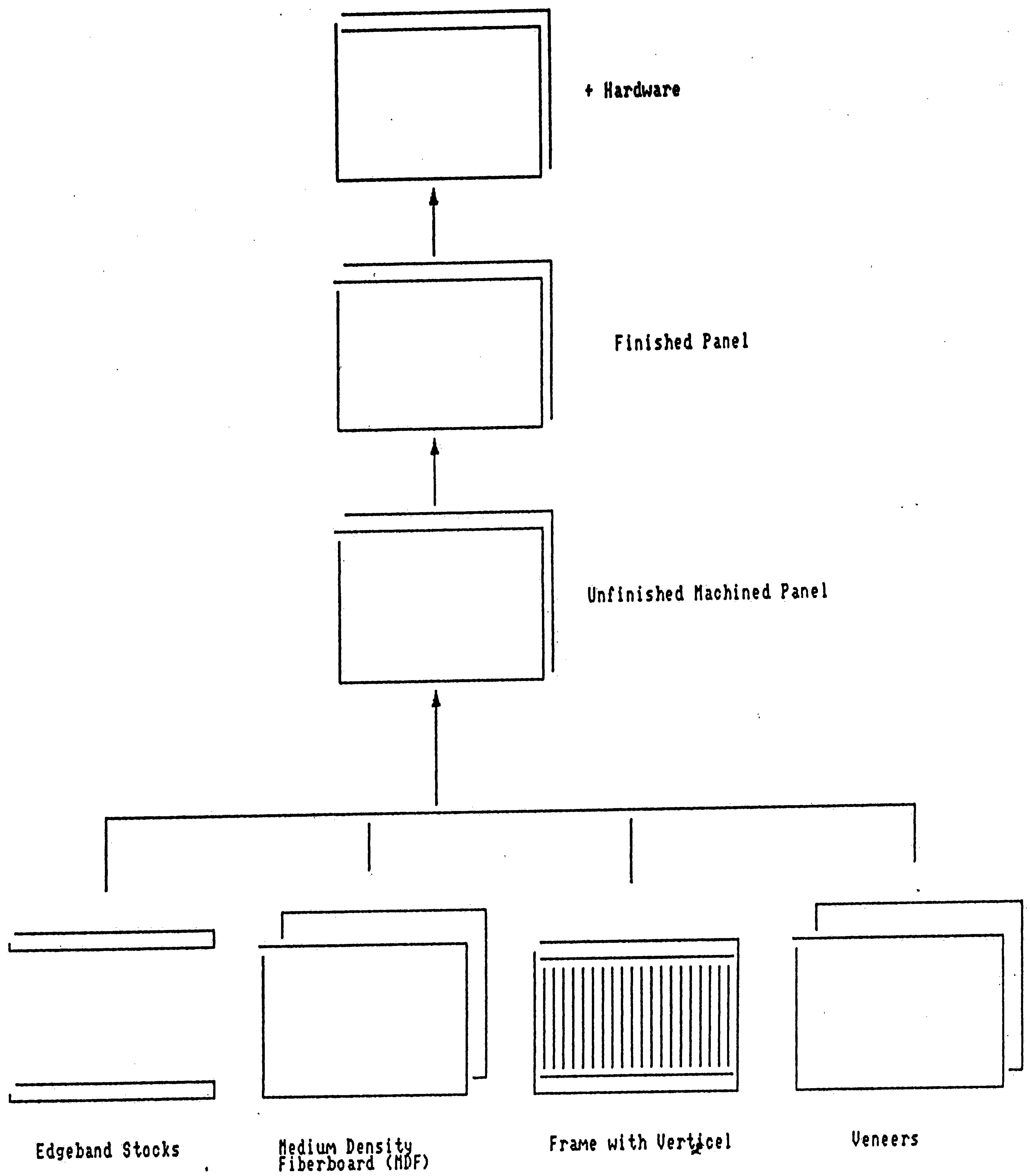


Figure IV.4 Structure of 5-layer ply panel maintaining the shape of the frame and other components in addition to making the panel feel solid by adding weight. Two medium density fiberboards(MDF) are then glued to the frame at both sides, one at each side. The MDF has much more density than a chipcore. Two veneers are glued to the MDF at both sides, again one at each side. One side of the panel serves as the top of a worksurface and the other side is the bottom.

The top veneer may be different (due to surface finish requirements) from the bottom veneer which is typically less expensive and of poorer quality. Edgebands are attached to some or all of the edges of the panel. The edgeband is a thin-narrow-long piece of wood which conceals the layers at the edge.

Drilling(Boring is the more commonly used terminology in the shop) operations are done on the required positions of the panel. After finishing operations, the panel is ready for assembly operations or shipping.

Dimensions

As mentioned earlier, a long machine set-up time is one of the major constraints which decreases machine efficiency, and, consequently, production rate. Since the major material to be processed is wood (which has relatively simple properties compared with metals), cutting speed or feed rate does not play as an important role as it does in metal cutting operation. The dimension of a part is a major parameter in setting-up the machine in the furniture industry. By grouping the parts together based on the dimension concerned, the set-up time(the total set-up time/the number of parts within a group) can be significantly reduced and the machine utilization can be increased.

By nature of a panel's shape, the primary dimensions are the width, the length, and the thickness. Dimensional variations in the products make it very difficult to determine standard dimensions and build a menu-driven screen to easily pick up the desired dimensions in classifying and coding items at a computer terminal. One approach taken is to enter the dimension of a part such that the integer digits of the dimension become a part of code.

Materials and Colors

Basically three types of materials - woods, fabrics and metals are used in the three different shops: a woodshop, a fabric shop, and a metal shop. Only the woods and the fabrics are used to manufacture panels. Frames are usually made of either Micro-lam or Popular. The Micro-lam is a less expensive wood than Popular. There are basically seven types of natural veneers in terms of materials (Mahogany, Oak, Walnut, Cherry, Maple, Elm, and Popular. Techgrain is also a widely used processed wood which has unique patterns (figures) on it. A pattern is very important from an aesthetic viewpoint of furniture and must be carefully put on the furniture. There are basically two types of patterns used. One is called a 'reverse slip match' in which each adjacent pattern has a different direction with each other, while a 'book match' pattern has the same direction. Plastic laminates are also widely used in panel making. About half of the 5-layer ply panels are covered by laminates.

Color is probably one of the most important attributes to be considered in the product list. However, in the same way as the dimensions, the color is also an important machine set-up parameter, especially in the finishing operation. There are basically three different colors: natural, red and brown. In veneers, color can be expanded to different shades, such as light red, medium red, dark red, etc. Laminates panel usually have eight different colors, namely white, beige, gray, black slate, amaranto, peach and taupe. Like veneers, many of these colors are also expanded.

4.3.2 Analysis of the Process Features

To determine process features of parts to be reflected in a GT code, the process routines of the parts must first be analyzed. Two possible methods to analyze the processes are considered. The first method is through a production flow analysis (PFA) [13]. PFA provides an clear formation of component-machine groups based on processes although there might be some difficulties in identifying bottle-neck machines which is crucial for a successful PFA. A comprehensive analysis of route sheets can provide an answer in seeking bottle-neck machines for PFA. However, a route sheet analysis does not verify whether the sorted groups are mutually exclusive or not. Because 5-layer and 3-layer ply panels are key components in the case company, they were chosen to be analyzed. In this thesis 5-layer ply panels are analyzed by means of production flow analysis while 3-layer ply panels are analyzed by route sheet analysis alone.

<u>Production Flow Analysis of 5-layer Ply Panels</u>

The procedure to conduct PFA is well documented [26] and consists of the following steps:

(1) Data Collection

(2) Sorting of Process Routings

(3) Production Flow Analysis

Data Collection

For this study the case company provided 207 samples of parts to be analyzed which are related to the 5-layer ply panels. The minimum data needed in the analysis are the part number and machine routing (operation sequence) for each part. These data are obtained directly from the route sheets which are provided by the case company.

Sorting of Process Routings

The second step is to arrange the parts into groups according to the similarity of their process routings. One easy way to accomplish this step is to code the data collected in step 1 onto index cards. One of the possible formats for these cards is illustrated in Figure IV.5.

A sorting procedure then would be used on the cards to manually arrange them into "packs". A pack is a group of parts with identical process routings. Some packs may contain only one part number, while others have dozens of part numbers. Each pack is given a pack identification number of letter.

Initially, 46 packs were made from the 207 samples,

QCIG404AFH4	---	Part Number
075/198/078/075/198/078/297	---	Machine Sequence
Panel, Side Component	---	Description

Figure IV.5 Pack Sorting Index Card

which means that all the parts are grouped into 46 groups based on identical process routings. This identical process routing means the exact same route sheets in terms of the types of machine processes, the number of times processed by the same machine, and the sequence of processes. All of the 46 packs determined in this research are listed in Appendix A.1.

It should be noted that the number of operations done by the same machine and the sequence and type of processes are considered in forming the packs. For instance, even though the machine processes for part A and B are the same, the two parts are grouped into different packs, because the horizontal boring process has been done only once in part A while part B requires that operation several times. In determining process attributes and grouping parts based on processes, the number of times and the sequence of machining processes are not the important factors to be considered. In addition, some of the packs listed in Appendix A.1 can be again grouped together to form a "combined pack". Here, the combined pack means a group of parts which need the same machining processes regardless of the sequence of machining processes and the number of times processed through a particular machine.

There were 31 combined packs made manually from the 46 original packs. Each pack by itself required the same types of machining processes. All the combined packs that were determined are listed in Appendix A.2.

As can be seen in Appendix A.2, the combined 31 packs can be roughly grouped together into six groups based on the type of processes, consisting of (1) frame making process, (2) veneer panel making process, (3) laminating panel making process, (4) finishing process, (5) MDF(medium density fiberboard)/chipcore cutting process and (6) the assembly process. The results of the analysis of six groups are listed in table IV.1 with the number of parts within the group and percentage proportions. Of the six types of processes, four types (frames, veneer panels, laminate panels and finishing operation) contributed 93.7 percent of the total, and are subsequently analyzed via production flow analysis.

Table IV.1 Group of Parts from 207 Samples

	QTY	%
frame	58	28.0
veneer pnl	48	23.2
laminate pnl	41	19.8
pnl finishing	47	22.7
MDF, chipcore	10	4.8
assemble top/bottom	3	1.5
===================	===	=====
Total	207	100.0

Production Flow Analysis

Based on the four types of parts/processes discussed in the previous section, a PFA chart is developed by using the rank order cluster(ROC) algorithm presented by King [41, 42, 43]. A computer program written in Turbo Pascal is developed (Appendix A.9) to form machine-component groups based on the ROC algorithm. Each pack of the first 28 packs indicated in Appendix A.2 and its associated processes are entered into the computer program and the initial machine-component (pack in this case) matrix is shown in figure IV.6. The row stands for the machine numbers which are converted from the machine codes being used on the route sheets. The relations between those two numbers are completely shown in the Conversion #1 colume of Appendix A.3. For example, machine 1 stands for Porter Crosscut Saw. The column stands for the pack ID numbers which are shown in Appendix A.2.

It is seen that the 1 entities(occurrences of the machining processes) are scattered all over the matrix in figure IV.6. There are definitely no machine-component groups formed in this initial matrix. After processing the ROC algorithm, the resulting matrix are obtained and shown in figure IV.7. The 1 entities are somewhat clustered along the diagonal of the matrix. However, it is still

Machine number

Pack number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
1	1		1																													1		1								1					1		
2	1		1	1																												1		1								1					1		
3	1		1							1																						1		1								1					1		
4	1		1													1																		1								1					1		
5												1	1	1	1		1																						1										
6												1	1	1	1		1				1																		1										
7												1	1																										1					1					
8																	1							1		1			1	1	1																	1	
9																	1							1		1				1	1										1							1	
10					1																			1	1			1	1				1			1	1											
11																								1	1								1			1					1							
12					1																			1	1								1			1	1				1								1
13					1														1					1	1			1	1				1			1		1										
14																								1	1			1	1				1			1												
15										1														1	1			1					1			1												
16																								1	1								1			1					1								1
17							1																1	1	1			1	1				1			1									1			
18					1			1	1		1													1	1			1					1			1	1											
19					1		1			1													1	1	1			1	1				1			1	1									1			
20					1													1						1		1			1	1	1						1											1	
21					1					1	1							1						1		1				1	1						1											1	
22					1													1						1		1				1	1						1				1							1	
23					1	1	1			1								1		1		1		1		1	1		1		1						1									1		1	
24																																							1	1				1	1				
25																																1										1					1		
26				1																												1										1					1		
27	1	1														1																										1					1		
28																																												1	1				

Figure IV.6 Initial Machine-Component Matrix
Each entry indentifies machine used in each pack.

Machine number

Pack number	42	47	1	16	2	3	34	32	4	10	24	5	37	29	46	7	26	31	48	18	6	20	27	22	36	33	25	28	23	30	11	41	9	8	49	19	38	17	39	12	13	14	15	21	44	45	40	35	43
27	1	1	1	1	1																																												
4	1	1	1	1		1	1																																										
2	1	1	1			1	1	1	1																																								
3	1	1	1			1	1	1		1																																							
1	1	1	1			1	1	1																																									
26	1	1						1	1																																								
25	1	1						1																																									
23										1	1	1	1	1	1	1	1	1	1	1	1	1	1	1																									
19										1	1	1	1	1	1	1									1	1	1	1	1																				
21										1	1	1	1				1	1	1	1										1	1																		
15										1	1														1	1	1	1																					
20											1	1	1	1			1	1	1	1										1																			
10											1	1	1	1											1	1	1	1																					
22											1	1	1				1	1	1	1										1		1																	
18											1	1	1												1	1	1	1			1		1	1															
12											1	1	1												1	1	1					1			1														
13											1	1		1											1	1	1	1								1	1												
17											1			1	1	1									1	1	1	1	1																				
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14											1			1											1	1	1	1																					
9											1						1	1	1											1		1						1											
16											1														1	1	1					1			1														
11											1														1	1	1					1																	
6																																						1	1	1	1	1	1	1					
5																																						1	1	1	1	1	1						
7																																							1	1	1				1				
24																																							1						1	1	1		
28																																													1	1			

Figure IV.7 Partially Grouped Machine-Component Matrix
Each entry identifies machine used in each pack.

difficult to form machine-component groups. One of the major reasons results from ancillary machines in the process. An ancillary machine is one that is not normally used for processing a particular part. This occurs when either the part requires a truly special process or the machine is misused by an inappropriate process plan. To get the diagonally clustered, mutually exclusive machine-component groups, these ancillary machines are excluded from subsequent analysis and are considered as special cases.

One of the easiest way to define ancillary machines is to count the frequencies of the machines being used among the samples and determine a machine which is less frequently used. The machine frequencies among the 207 samples are counted from the index cards and they are listed in Appendix A.4.

Machines which are used less than 15 percent of the total samples (31.05 times of frequency) are considered as ancillary machines and they are marked by an asterisk(*) next to the frequency in Appendix A.5. There were found to be 14 ancillary machines out of the 49 machines used for the 207 samples, which indicated a 28.6 percent reduction of machines to be analyzed by excluding the ancillary machines. The minimum number of usage of the major (nonancillary) machines turns out to be 40 in this case. As it is seen in the table IV.1, 93.7 percent of the samples are frames and panels, and the minimum number of parts are 41 (laminate panels). Therefore, it can be concluded that all of the major machines in Appendix A.5 are quite standard machines in making frames and panels.

The resulting PFA chart after excluding ancillary machines is shown in figure IV.8, where the row also stands for machine numbers which are updated after excluding ancillary machines and listed in Appendix A.3 (Conversion #2 column), and the column stands for pack ID numbers. Three nicely formed mutually exclusive machine-component groups are found in the figure IV.8. The first group located in the upper-left corner of the chart contains frames and six different machines are allocated exclusively. The second group in the middle of the chart is a panel group and 13 machines are allocated exclusively for this group. The last group indicated in the lower-right position of the chart corresponds to the finishing processes and six machines are assigned.

The frame and finishing operation groups are nicely clustered and do not need to be further divided into subgroups. However, the panel group contains both veneer and laminate panels, and their processes are quite different.

Machine number

Pack number	23	24	1	2	19	17	10	3	21	16	9	12	25	14	15	11	20	18	13	22	5	4	8	6	7
1	1	1	1	1	1	1																			
2	1	1	1	1	1	1																			
3	1	1	1	1	1	1																			
4	1	1	1	1	1																				
25	1	1	1																						
26	1	1				1																			
27	1	1				1																			
20							1	1	1	1	1	1	1	1	1										
23							1	1	1	1	1	1	1	1											
21							1	1	1	1	.	1	1		1										
22							1	1	1	1	1	1	1		1										
19							1	1	1					1		1	1	1	1						
10							1	1	1					1		1	1	1	1						
18							1	1	1							1	1	1	1						
12							1	1	1							1	1	1							
13							1	1						1		1	1	1	1						
8							1			1	1	1	1	1	1										
9							1			1	1	1	1		1										
17							1							1		1	1	1	1						
14							1							1		1	1	1	1						
15							1									1	1	1	1						
11							1									1	1	1							
16							1									1	1	1							
6																				1	1	1	1	1	1
5																				1	1	1	1	1	1
7																				1	1	1			
24																				1					
28																									

Figure IV.8 Partially Grouped Machine-Component Matrix
Each entry identifies machine used in each pack.

The veneer and laminate panel groups are not separated since there might be common machines being used for both types of panels. Because of their high usages, these machines are called "bottle-neck machines" and the approach to this bottle-neck machine problem was previously discussed in chapter 1 [43].

In order to separate the veneer and laminate panel group, the bottle-neck machines being used for both of these panels should be assigned to each group separately. One method of assigning bottle-neck machines to each group is to provide as many of the duplicated bottle-neck machines as possible to the extent that each pack operation is performed by one such machine. Therefore, the bottle-neck machines are fully relaxed and decomposed. The ROC algorithm is then reapplied to the relaxed, decomposed matrix to form new machine-component groups. After new groups are formed, a further operation is now required to recompose the duplicated bottle-neck machines. The duplicated machines of a particular type may, if they occur in the same machine group in the final solution generated by the ROC algorithm, be recomposed into a single machine. Recomposing is done by simply aggregating the same type of duplicated machines. New machine-component groups are then formed without the constraint of bottle-neck machines.

In figure IV.8, four machines may be identified as bottle-neck machines, namely machine 10, 3, 21 and 14, because of their high usage. These four machines are then decomposed according to the number of packs (The first colume in figure IV.8 shows pack I.D. number.) assigned to those machines. Sixteen packs are assigned to machine 10, nine packs to machine 3, eight packs to machine 21, and another eight packs to machine 14. Therefore, there are 16 duplicate machines of machine 10, 9 duplicates of the machine 3, 8 duplicates of machine 21, and another 8 duplicates of machine 14. The decomposed matrix is shown in figure IV.9. The corresponding duplicated machine numbers in figure IV.9 are as follows:

Machine 26 thru 41 are duplicates of machine 10.

Machine 42 thru 50 are duplicates of machine 3.

Machine 51 thru 58 are duplicates of machine 21.

Machine 59 thru 66 are duplicates of machine 14.

The resulting matrix after the ROC algorithm was applied to the matrix in figure IV.9, indicates the four mutually exclusive machine-component groups as shown in figure IV.10. Recomposing the matrix of figure IV.10 results in Figure IV.11 which shows the final machine-component group matrix.

Machine number

Pack number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66
1	1	1															1		1				1	1																																									
2	1	1															1		1				1	1																																									
3	1	1															1		1				1	1																																									
4	1	1																	1				1	1																																									
5				1	1	1	1	1														1																																													
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12											1							1		1										1													1									1														
13											1		1					1		1											1													1																		1					
14											1		1					1		1												1																															1				
15											1		1					1		1													1																																		
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17											1		1					1		1															1																													1			
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25	1																						1	1																																										
26																	1						1	1																																										
27																	1						1	1																																										
28																																																																		

Figure IV.9 Machine-Component Matrix with Decomposed Bottle-neck Machines
Each entry identifies machine used in each pack.

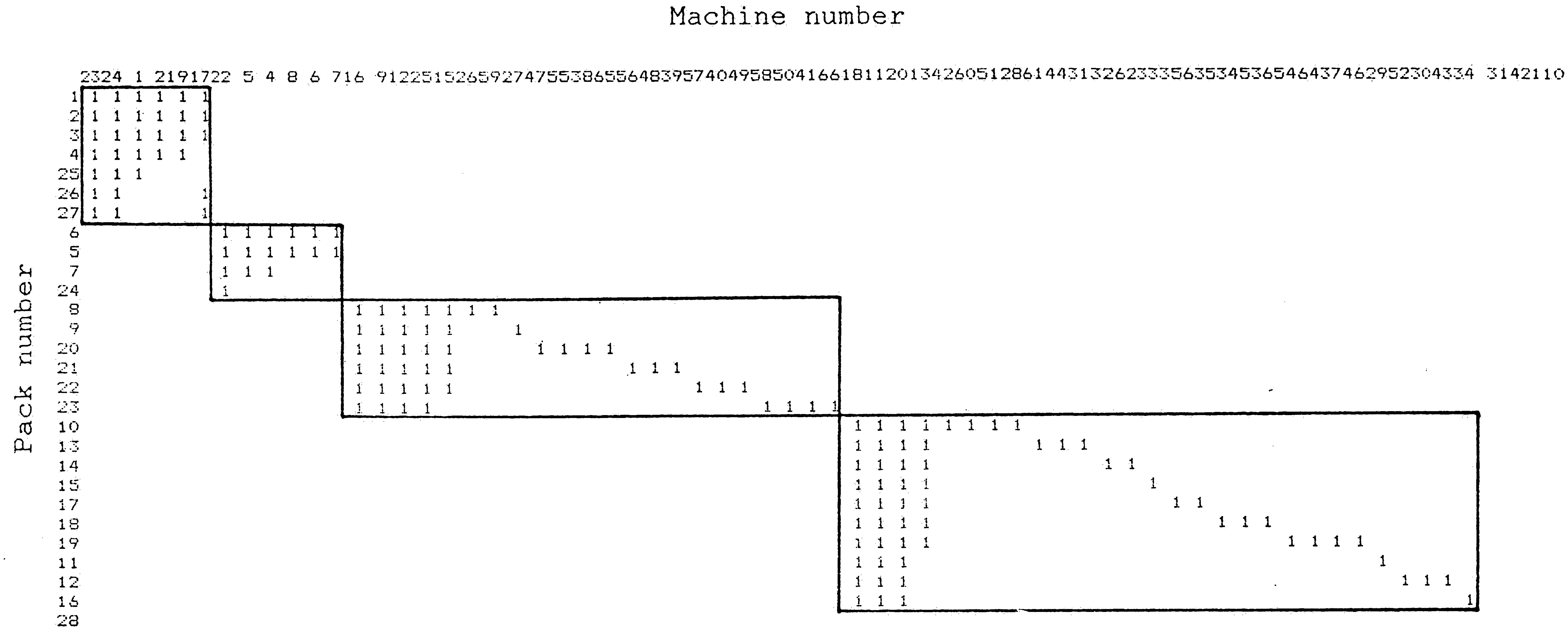

Figure IV.10 Machine-Component Matrix with Decomposed Bottle-neck Machines
Each entry identifies machine used in each pack.

Machine number

Pack number

	23	24	1	2	19	17	11	20	10	18	3	13	14	21	22	4	5	6	7	8	16	9	12	25	26	15	27	28	29
1	1	1	1	1	1	1																							
2	1	1	1	1	1	1																							
3	1	1	1	1	1	1																							
4	1	1	1	1	1																								
25	1	1	1																										
26	1	1				1																							
27	1	1				1																							
19							1	1	1	1	1	1	1	1															
10							1	1	1	1	1	1	1	1															
13							1	1	1	1	1	1	1																
18							1	1	1	1	1	1		1															
12							1	1	1	1	1			1															
17							1	1	1	1		1	1																
14							1	1	1	1		1	1																
15							1	1	1	1		1																	
11							1	1	1	1																			
16							1	1	1	1																			
6															1	1	1	1	1	1									
5															1	1	1	1	1	1									
7															1	1	1												
24															1														
20																					1	1	1	1	1	1	1	1	1
22																					1	1	1	1	1	1	1	1	
21																					1	1	1	1	1	1	1	1	
8																					1	1	1	1	1	1			1
9																					1	1	1	1	1	1			
23																					1	1	1	1	1		1	1	1
28																													

Figure IV.11 Final Machine-Component Matrix
Each entry identifies machine used in each pack.

Once again, it should be noted that machine 26 is the same machine as machine 10, and the only difference is that these machines are exclusively used for different groups. In the same way, machine 27 is the same as the machine 3, machine 28 is the machine 21, and machine 29 is the machine 14.

There are four mutually exclusive machine-component groups formed in the final matrix (Figure IV.11). Machines within a particular group are used exclusively for parts of the group. Therefore, these machines become standard processes for the parts of a group.

Production flow analysis (PFA) helps to determine a standard process of a group by developing exclusive machine-component groups. One drawback of PFA may be encountered here again. Because PFA is based on existing process routings, there is no gaurantee that the resulting standard process plans are optimal.

As seen in the final PFA chart in figure IV.11, there are four mutually exclusive machine-component groups formed, namely frames, veneer panels, laminate panels, panel finishing operations, and their associated machine groups. Each machine group is dedicated to the its associated component groups. Based on these machine-component groups,

Machine number

Pack number	23	24	1	2	19	17	11	20	10	18	3	13	14	21	22	4	5	6	7	8	16	9	12	25	26	15	27	28	29
1	1	1	1	1	1	1																							
2	1	1	1	1	1	1																							
3	1	1	1	1	1	1																							
4	1	1	1	1	1																								
25	1	1	1																										
26	1	1				1																							
27	1	1				1																							
19							1	1	1	1	1	1	1	1															
10							1	1	1	1	1	1	1	1															
13							1	1	1	1	1	1	1																
18							1	1	1	1	1	1		1															
12							1	1	1	1	1			1															
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16							1	1	1	1																			
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22																					1	1	1	1	1	1	1	1	
21																					1	1	1	1	1	1	1	1	
8																					1	1	1	1	1	1			1
9																					1	1	1	1	1	1			
23																					1	1	1	1	1		1	1	1
28																													

Figure IV.11 Final Machine-Component Matrix
Each entry identifies machine used in each pack.

Once again, it should be noted that machine 26 is the same machine as machine 10, and the only difference is that these machines are exclusively used for different groups. In the same way, machine 27 is the same as the machine 3, machine 28 is the machine 21, and machine 29 is the machine 14.

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Production flow analysis (PFA) helps to determine a standard process of a group by developing exclusive machine-component groups. One drawback of PFA may be encountered here again. Because PFA is based on existing process routings, there is no gaurantee that the resulting standard process plans are optimal.

As seen in the final PFA chart in figure IV.11, there are four mutually exclusive machine-component groups formed, namely frames, veneer panels, laminate panels, panel finishing operations, and their associated machine groups. Each machine group is dedicated to the its associated component groups. Based on these machine-component groups, one can easily determine the standard process for each group. A machine which is not included in this standard process is considered as a special process. The standard and special processes for those four groups are listed in Appendix A.5.

Up to this point, 5-layer ply panels were analyzed by means of the Production Flow Analysis (PFA). Among the 207 samples, four different groups were formed based on the process and their standard process plans are determined. Any special process is determined by simply counting the frequency of the process. A process which occurred less than a certain amount of times (15 percent of the sample population in this case) is considered as a special process. The obtained standard and special process features will be reflected in developing GT codes. Since 3-layer ply panels are also key components in the case company and their variations are even larger than 5-layer panels, their processes are analyzed in the following sections.

Route Sheet Analysis of 3-layer Ply Panels

A process of 3-layer ply panels is analyzed by means of Route Sheet Analysis (RSA) which has the following basic steps:

(1) Data Collection

(2) Sorting of Process Routings

(3) Analysis

Data Collection

The sample population the case company provided consisted of 242 parts. The minimum data needed for analysis are the part number, the part description and the machine routine (process sequence) of each part. All such data was obtained from the route sheets provided by the case company.

Sorting of Process Routings

The second step is to arrange the parts into groups according to the similarity of their process routings. One easy method of doing this had been demonstrated in the previous 5-layer ply panel analysis. This method uses index cards to code the data collected in step 1. A sorting procedure would be used on the cards to arrange them into "packs". A pack is a group of parts with identical process routing. This identical process routing does not necessarily mean the same number of machine processings or the same sequence of processes. The type of machine processes (more specifically, the name of machines) was used for the analysis.

It was found that for the 242 parts analyzed, there are basically two different types of machine process. The first type of process is that the final parts, (e.g. doors of cabinet), are made from the already existing 3-layer ply panels. The major processes consisted of cutting operations to size, and various drilling or routing operations. The second type of processes consisted of final parts made from raw materials such as veneers and MDFs. In this case, the panel-making processes should precede the processes mentioned in the first case. This second set of processes was found to occur in 129 samples, while the first case type had 97 samples. The remaining 16 samples out of 242 are not included in either case, and consisted of finishing operations. Since the proportion of the total samples are very low (16 parts/242 parts = 6.6%), they are considered as a special case.

Sorting 3 Ply Panel-making Processes

The 3 ply process is relatively simple but does have some minor variations. There were found to be 129 samples which require only 9 types of different machine processes. The packs are listed in Appendix A.6. 8 different machines were used for these 129 parts, and their frequencies and descriptions are shown in table IV.2. Of the 8 machines, only 4 machines are used very widely (more than 120 parts out of 129 parts) and the other 4 machines are used only for a small number of parts (less than 6 parts). It is clear that the widely used 4 machines are standard process machines.

Table IV.2 Standard Machines in 3 Ply Panel-making Process

Machine	Description	Frequency	
008	Timesaver	5	
010	Tannewitz table saw	1	
075	B&G crosscut saw	129	*
078	Kuper veneer splicer	121	*
198	Bauerle veneer guillotine	129	*
297	Wemhoner auto flat press	128	*
298	Tyler colder press	3	
324	Sheer table saw	1	

- Standard machines are marked by an asterisk.

<u>Sorting Case Body Component-making Processes</u>

Unlike panel-making processes, there are a significant number of variations in the component-making processes. Based on the sample data there are 69 different packs made from the total 223 parts concerning these processes. Once again, each pack used the same type of machining processes. The 69 packs are listed in Appendix A.7. Of all the machines used for processing the 223 parts, some machines are used only for the limited number of parts and their frequencies are relatively low. These machines are considered as ancillary machines, and are considered as a special case. To define the ancillary machines, the frequencies of the machines which are used on each of the 223 samples are counted and listed in table IV.3. The machines which are used less than 10 percent of total 223 samples are considered as ancillary machines. There are 27 ancillary machines out of 40 total machines being used. In other words., 13 major machines cover more than 90 percent of the samples. By excluding these ancillary machines from the analysis, the new pack of parts can be obtained again, with each of these new packs having the same machining processes. The new packs are listed in Appendix A.8. There were 44 new packs obtained.

The advantage by excluding the ancillary machines from the analysis can by summarized as follows: (1) the reduction of the packs to be analyzed is 36.2 percent (44 packs from 69 packs), and (2) the reduction of the machines used is 67.5 percent (13 machines from 40 machines).

Analysis of the Panel-making Processes

The panel-making processes are relatively simple and there were found to be only 9 different packs according to the type of processes involved as shown in Appendix A.6.

Table IV.3 Machine Frequency List

Machine	Description	Frequency	
001	Porter crosscut saw	1	
002	Mattison rip saw	1	
003	Bauerle jointer	1	
007	Tannewitz table saw	47	*
008	Timesaver	5	
010	Tannewitz table saw	6	
011	Tannewitz bandsaw	1	
012	Tannewitz table saw	93	*
017	Bacci mortise machine	1	
019	Root horizontal boring machine	36	*
020	Root vertical boring machine	114	*
026	Porter router	19	
027	Bauerle shaper	3	
033	Sicotte vertical boring machine	5	
035	Postform laminate saw	2	
036	Mattison stroke sander	5	
040	Wemhoner case clamp	2	
045	Mattison edge sander	22	
056	Olimpic double edgebander	203	*
057	Costa tenoner	216	*
058	Homag tenoner/edgebander	7	
066	Oakley sander	1	
067	Oakley sander	37	*
084	Articulated overhead router	5	
086	Articulated overhead router	32	*
091	Hi frequency generator	41	*
093	Root belt sander	41	*
202	Stanley hand router	15	
298	Tyler cold press	3	
300	Heeseman auto sander	44	*
302	Weeke boring machine	17	
322	Weining planer/molder	1	
323	Ekstrom Carlson overhead router	53	*
324	Sheer table saw	1	
339	Offline spray booth, wood	3	
340	Paint line wood	1	
907	Bench, woodshop sub-assy	2	
908	Bench, woodshop machine	12	
909	Bench, woodshop roughing	1	
914	Bench, woodshop laminating	37	*

- Standard machines are marked by an asterisk.

Furthermore, pack 2 basically has the same processes as pack 1. The only difference between those two packs is the material of veneers used. In pack 1, the veneers of both front and back are made of different kind of wood, while the same kind of veneers are used in the pack 2. Once the pact 1 and pack 2 are combined together, the combined pack contains a total of 111 parts out of 129 samples (86 %).

In addition, the analysis indicated that there are 7 parts which do not require veneer splicing operation (078) in pack 3, and these parts can also be included in the pack 1. or 2. Thus, only four machines (075, 078, 198, 297) account for 91.5 percent of the total samples (118 parts / 129 parts).

The other 5 packs (pack 4 through 9) need other machine processes besides the above four machines. Because their proportions to the total parts are so low(8.5 %), they are considered as special parts which require special machining processes.

The standard process of panel-making can be summarized as follows:

Sequence	Description	Machines Used
010	Cut veneer to length	075
020	Cut veneer to width	198
030	Splice veneer to width	078
040	Cut veneer to length	075
050	Cut veneer to width	198
060	Splice veneer to width	078
070	Press panel	297

It should be noted that the process 040 through 060 would not be necessary in pack 2, because the same veneers are used for both the front and the back of the panel.

Analysis of the Case Body Component-making Processes

Unlike the panel-making processes, there were found to be variations in the component-making processes (refer to Appendix A.8). There are 44 different type of packs according to the type of processes within this group. There are two distinguishable dominating machining processes throughout the group. These processes are the cutting process to size the panel and the edgebanding process. The machines used for these purposes are the Costa Tenoner (057), the Olimpic double edgebander (056), and the Homag tenoner/edgebander (058). The Homag tenoner/edgebander is a powerful machine which performs the cutting and edgebanding operations at the same time. However, for the sample size considered in this investigation, only 5 parts out of

223 total parts were processed by this machine while 202 parts were processed through both the Costa tenoner (057) and the Olimpic double edgebander (056). Therefore, the process plans using the Homag tenoner/ edgebander are not considered as standardized plans. It is recommended that only the Costa Tenoner and the Olimpic double edgebander be used for all the cutting to size and the edgebanding operations in 3-layer ply panel processes. Another consideration is that some parts only require either sizing or edgebanding operations, not both. Within the scope of this study it was found that 12 parts of 223 total parts do not require the edgebands and are considered as a special case. In addition, 2 parts did not require the cutting to size operations and this can only happen when the size of the raw panel is the same as that of a required component. This situation is also considered a special case and excluded from subsequent analysis. The advantage by excluding the above special cases (21 parts/223 parts = 9.4 %) from the analysis is the reduction of the packs to be analyzed by 41 percent (26 packs from 44 packs). As a result, there are 202 major parts, all of which need both cutting to size and edgebanding operations using the Costa Tenoner (057) and the Olimpic double edgebander. The analysis was done on these parts.

It was initially determined that there are 26 different packs in this standard group - a group which uses both machine 057 and 056, i.e. pack 1 through pack 26 in Appendix A.8 -, and a total of 13 different machines are used for this group.

Those 13 machines can be categorized into 7 groups according to their functions, and listed in table IV.4.

Table IV.4 Functional Machine Groups in Cabinet Body Component-making Process

Function	Machine	Machine #	Freq.
1.Tenoner	Costa tenoner	057	216
2.EB	Olimpic double edgebander	056	203
3.Saw	Tannewitz table saw	007	47
	Tannewitz table saw	012	93
4.Boring	Root horizontal boring mach.	019	36
	Root vertical boring mach.	020	114
	Bench, woodshop laminating	914	37
5.Glue	Hi frequency generator	091	41
6.Routing	Articulated o/h router	086	32
	Ekstrom Carlson o/h router	323	53
7.Sanding	Oakley sander	067	37
	Root belt sander	093	41
	Heeseman auto sander	300	44

The 7 functional machine groups constitute a standard process of cabinet body components. The standard plans are summarized in Table IV.5.

Table IV.5 Standard Process Plans for Cabinet Body Components

Sequence.	Description	Machines Used
010	Cut to width and length	057
020	Edgeband sides and/or top	056
030	Part	007, 012
040	Sand faces and/or edges and/or pulls	067, 093, 300
050	Glue pulls to doors (Doors only)	091
060	Rout for locks, hinges, and etc.	086, 323
070	Bore/Counterbore holes	019, 020, 914

- It should be noted that the sequence can be different depending on the type of parts.

V. A GT Code for Furniture Production

5.1 Proposed GT Code Structure

The GT code proposed for furniture production will have 20 to 21 digits, at most 22 digits. A major benefit of this lengthy GT code is for the integration of information flow within a company. However, this lengthy code has drawback in that it often causes errors in using it. Furthermore, because the code contains a wide range of information, the total length of code is not always useful for people who have special interests. These drawbacks are minimized by segmenting a code to functional subcodes. Each functional code can either be used separately for the different purposes or combined to be one code for the intergration of information flow.

As discussed earlier in section 4.3 (Figure IV.3), the resulting code structure will have four functional sections to be easily used for different departments. Each section of code is connected to each other section by a hyphen and can be separated and used independently for the different purposes. Details of these four sections are discussed in the following sections.

Functional Group/Hierarchy Code

This functional section of code will replace many of the functions of the conversion number which currently identifies a line of product and its function in the case company. This section consists of four digits. The first two digits are devoted to the identification of a family to which the part belongs. According to the case company's product catalog and the sales report, nine distinctive families are easily formed. These nine groups also contain the mainstream of the current conversion numbering system under condition that the objects to be coded are furnitures. The nine families and their portions in sales are listed as follows:

1.	Morrison system	27.6 %
2.	Zapf system	23.1 %
3.	New Hannah system	11.9 %
4.	Stephens system	3.4 %
5.	Office seatings	17.7 %
6.	Desks & Credenzas	6.5 %
7.	Side chairs	4.1 %
8.	Lounge seatings	2.6 %
9.	Tables	2.1 %

The above nine groups covers 98 percent of the company's total annual sales. Products which are not included in the above nine groups are considered as general products and grouped into a separated group. It should be noted that assigning two digits for the ten groups(including the general group) is quite generous, which means that this family group can be expanded to more detail without adding more digits in the code structure.

The last two digits serves to identify the hierarchical production level and function of parts or products. The third digit identifies the level of parts. There are five levels of parts depending on how much they are assembled, that is, groupings, assemblies, sub- assemblies, components, and raw materials. Each of these levels were defined and discussed in detail in section 4.3.1. Each of these levels will be explored to the detailed final parts and the forth digit will identify these final parts.

Dimension Code

The second functional section of code proposed is devoted to identifying the dimension of a part. Five digits are assigned for this purpose. Because most of the important parts of furniture - especially five- and three-layer ply panels - have hexahedron shapes, the length, width and the thickness are the most important dimensions to be considered. The first two digits of the dimension section are assigned to the length, the third and forth digits to the width, and the last, fifth digit is the the thickness.

The dimension section of code has a polycode (independent) structure. It should also be noted that the decimals are ignored and only integers will appear in the code.

Material/Color Code

The dominating material in the case company is wood. Other materials include fabrics which are used as upholsteries, and metals which are used as furniture hardwares, such as hinges and legs. The first two digits of this functional section of code will be used for coding materials.

It should be noted that confusion might occur when coding partially assembled parts made of different materials. For example, a veneer 5-layer ply panel is composed of several different materials. The frame is typically made of a different type of wood than that from which the veneer is made. In addition, the face veneer is different from the backing veneer. Furthermore, most of the 5-layer ply panel have a verticel core. When trying to code these types of parts, one is faced with the problem as to what material should be coded. The following definitions were applied to materials to be coded:

1) A material of which a main functional area of a part is made.

2) A material surrounding a part

3) The most dominating material

Color is also an important feature of finished furnitures. There are variations in colors for the same finished product and it is important to identify the color accurately and code it correctly for the finished products.

<u>Process Code</u>

The last functional section of the proposed GT code is devoted to the process features of a coded part. This section contains comprehensive information about process features of a part, and contributes to the manufacturing activities, such as process planning, machine scheduling, etc. There were two distinctive facts to be considered in the processes of the case company. The first one is that the process of manufacturing furniture is uniquely different from the metal-working industry. As mentioned earlier, the whole flow of furniture processing is assembly-oriented. The process code is thus assembly process oriented rather than cutting operation oriented. The other distinctive fact is that the condition of manufacturing basic components is relatively simple and follows a quite fixed sequence. The standard process plans are thus fairly easily formed and can be reflected in the GT code. This feature is particularly attractive in further developing a CAPP system since the resulting GT code could be directly entered into a CAPP system.

Four major types of components have been analyzed in this investigation, namely a frame, a 5-layer veneer panel, a 5-layer laminate panel and a 3-layer ply panel. Because of the differences in processes among those components, the code structure developed for each type of component is different. The frame has 3 digits of code to reflect it's process features. The first digits indicates whether this component follows a standard process plans, and the second digit indicates whether it has a verticel stuffing. The last digit is assigned to the special operations required for the frames. Veneer and laminate panels have more complicated processes than frames. Six digits are assigned for the process features of those panels. The function of each digit is shown in figure V.1.

The 3-layer ply panel also has 6 digits for identifying its process features. The function of each digit is shown in figure V.2.

The design features of 5- and 3- layer ply panels and their associated process features have been comprehensively

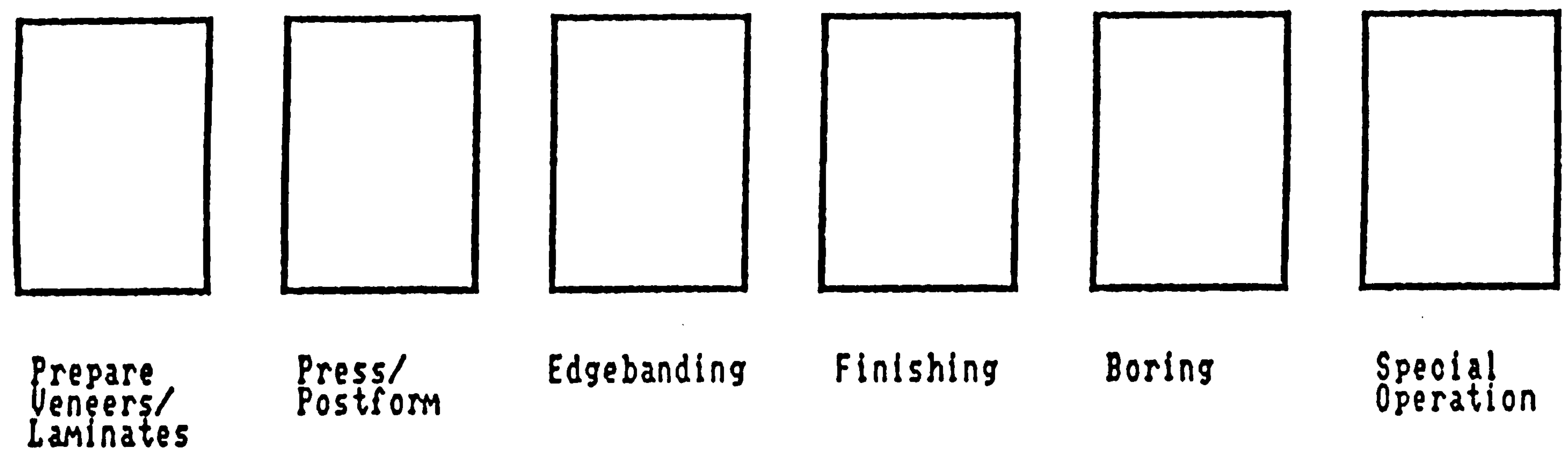


Figure V.1 Proposed Code Structure of 5-Layer Ply Panel

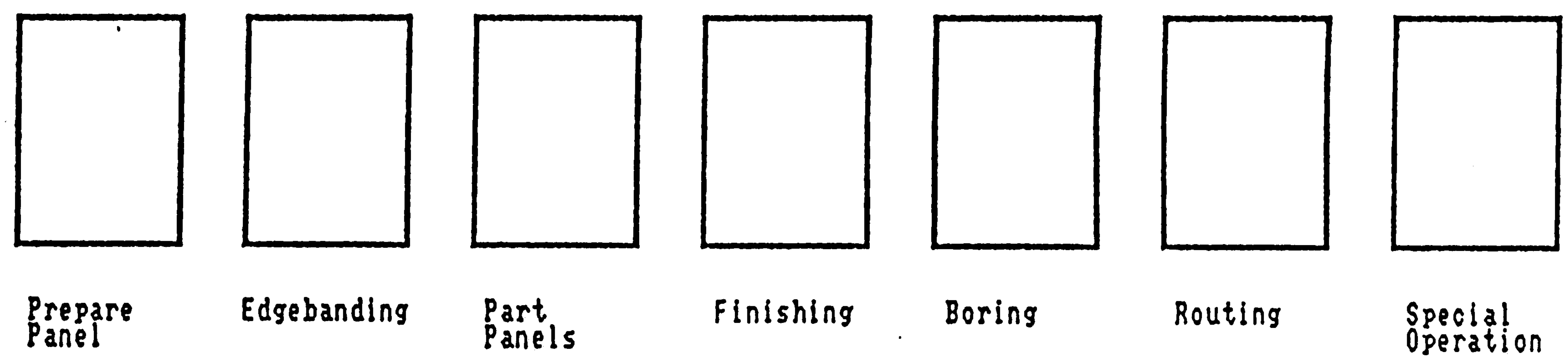


Figure V.2 Proposed Code Structure of 3-Layer Ply Panel discussed in conjunction with the current systems of the case company and a possible generic code structure was proposed for furniture production. While many of the commercially available GT systems are designed within the viewpoint of a metal-working industry, they are not necessarily appropriate for a furniture production industry. The ability of the DCLASS system to be highly tailored to meet a user's specific needs and its ease of integration with an existing system makes it an appropriate tool for a furniture company. After acquiring the necessary knowledge about the design and process features, the development procedure of a GT-based classification and coding system within a DCLASS environment usually follows the steps shown in figure V.3.

Writing a source file and processing in DCLASS is quite straightforward. Designing a tree and code structure, however, requires not only a extensive knowledge about both design and process aspects of a part, but also the realization of company's needs in terms of usage of a resulting code. Therefore, the success of developing a new classification and coding system largely depends on how to arrange the information effectively and efficiently in the form of a tree structure. The remainder of this chapter is devoted to this first step - designing tree and code

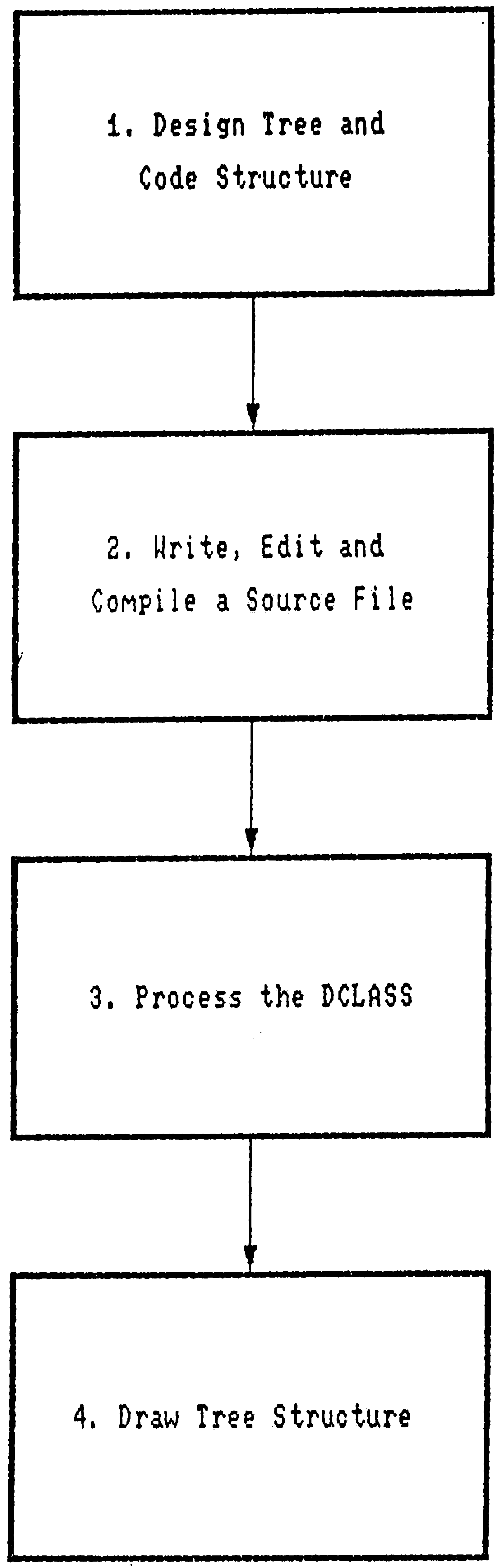


Figure V.3 Development Procedure of Classification and Coding System under DCLASS Environment structures. The intent of this research is to develop a generic GT code for furniture production. The case company is used to illustrate applications of the proposed GT code.

5.2 Developing Tree and Code Structure

According to the code structure proposed, an overall tree was designed which consists of 4 functional subtrees. The subtrees were (1) a functional specification tree, (2) a dimension tree, (3) a material/color/finish tree, and (4) a process selection tree. Each of these functional subtrees were designed to match with the corresponding section of the proposed code structure. These subtrees also have their detail sub-subtrees and their relationships are presented in figure V.4 along with a format of a code. The structure of each of these detailed sub-tree are discussed in the following sections.

5.2.1 Family Selection Sub-tree

A family tree structure where a part or product functionally belongs to is presented in figure V.5. It is a hierarchical mutually exclusive path tree (E-tree), which indicates that one has to choose only one path through the tree. The first two positions of the code are assigned for this purpose, and their relationships are presented in

```
                                                          Family
                                                          selection
                                    Functional          :----------------
                                    spec.              %:  Production
                                 :---------------------:  level &
                                 :                     :  function
                                 :                     :-----------------
                                 :
                                 :  Dimension
                                 :------------------
                                 :
   Part                          :                        Material
   classification              %:  Material/Color/    :-----------------
 -----------VW-----------------:  Finish             %:  Color
                                 :---------------------:-----------------
                                 :                     :  Finish
                                 :                     :-----------------
                                 :
                                 :                         Frame
                                 :                     :-----------------
                                 :  Process            :  Veneer panel
                                 :  selection         1:-----------------
                                 :---------------------:  Laminate panel
                                                       :-----------------
                                                       :  3-ply panel
                                                       :-----------------
```

Figure V.4   Part Classification Main Tree

```
                       General "GE"
                      :-----------------
                      :                          [MO]
                      :                  Morrison "MO"
                      :                 :-----------------
                      :                 :           [ZF]
                      :                 :  Zapf "ZF"
                      :  Designer's     :-----------------
                      :  system       l:           [NH]
                      :-------------------:  New Hannah "NH"
                      :                 :-----------------
   Family             :                 :            [ST]
   selection        l:                 :  Stephens "ST"
  -------------------:                 :-----------------
                      :
                      :                   Office seating
                      :                   "OS"
                      :                 :-----------------
                      :                 :  Side chair "SC"
                      :  Seatings      l:-----------------
                      :-------------------:  Lounge seating
                      :                 :  "LS"
                      :                 :-----------------
                      :
                      :                   Desk/Credenzas
                      :                   "DC"
                      :  Desks & Tables l:-----------------
                      :-------------------:  Table "TB"
                                        :-----------------
```

Figure V.5 Family Selection Sub-tree

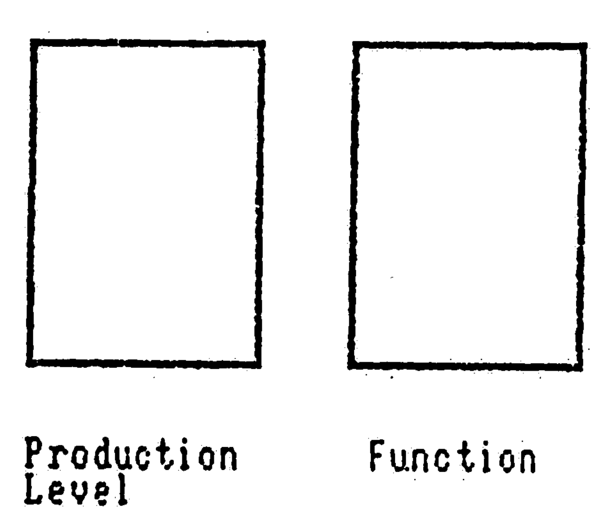
table V.1.

Table V.1 PRODUCT FAMILIES

FAMILY	DESCRIPTION
GE	General parts
MO	Morrison system
ZF	Zapf system
NH	New Hannah system
ST	Stephens system
OS	Office seatings
SC	Side chairs
LS	Lounge seating
DC	Desks/Credenzas
TB	Tables

5.2.2 Production Level and Function Sub-tree

According to the definition of a hierarchical production level and function, a tree structure for production level and function is presented in figure V.4. This is also a mutually exclusive tree structure. The code is alpha-numeric, and has a hierarchical structure (monocode). The format of the code is shown in the following sketch.



The first code element (alphabetic letter) stands for the production level and may assume one of the following:

A	Grouping
B	Assembly
C	Sub-assembly
D	Component
E	Raw material

The next numeric digit identifies the detailed function of a part on the condition of a particular production level. The relationships are found within the quotation marks in figure V.6.

5.2.3 Dimension Sub-tree

Three features of dimension - length, width and thickness - are reflected in the second section of the code. Five digits (two digits for each length and width, and one digit for thickness) are assigned to this section. The dimension code has a polycode structure, which means that the first two digits stands for length, the next two digits for width, and the last digit for thickness. The resulting tree structure is shown in figure V.7. The dimension tree is somewhat different from either the family selection tree

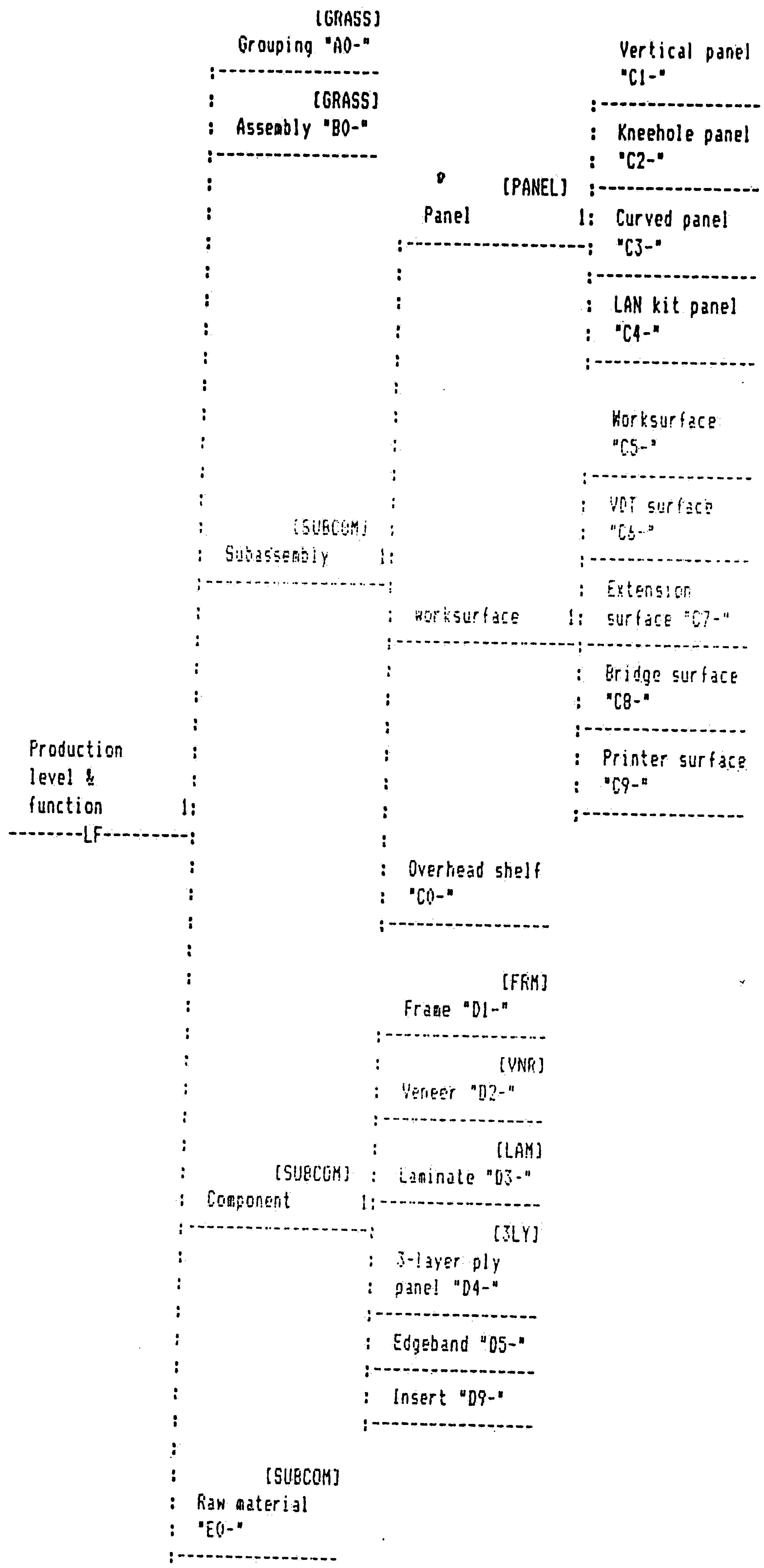


Figure V.6 Production Level and Function Sub-tree

```
                            LEN Enter
                           V length of part
                          :-----------------
                          :  ADD CODE &LEN
                          :C 2.0 NO PERIOD
                          :-----------------
                          :  WID Enter width
                          :V of part
                          :-----------------
     Dimension           %:  ADD CODE &WID
---------DM---------------:C 2.0 NO PERIOD
                          :-----------------
                          :  THK Enter
                          :  thickness of
                          :V part
                          :-----------------
                          :  ADD CODE &THK
                          :C 1.0 NO PERIOD
                          :-----------------
```

Figure V.7   Dimension Sub-tree

or production level & function tree in that one may input the values of dimension into the system rather than selecting a descriptive branch. Once a user inputs the dimensions - length, width, and then thickness separately -, the DCLASS program selects an automatic decision branch and generates a code. This code consists of the first two (one in thickness) digits without a decimal point.

5.2.4 Material Sub-tree

The dominant material in a furniture plant is non-metal, especially wood. Other forms of materials (e.g. plastic laminates and fabrics) are also widely used. The general material taxonomy based on non-metals and their associated tree structure as developed is indicated in figure V.8. It is also a hierarchical mutually exclusive path tree structure. Material families and their associated codes are shown in table V.2.

Table V.2 MATERIAL FAMILIES

FAMILY	DESCRIPTIVE TITLE
A	Metals
B	Woods
C	Textile fibers
D	Plastics
E	Rubbers/Elastomers
G	Glasses

- Material -MA-
  - (GRASS) Grouping/Assembly "+-00"
  - (SUBCOM) Subassembly/Component/Raw material
    - Metal "+-A0"
    - Non-metal
      - Fibrous material
        - Wood
          - Natural wood
            - Mahogany "+-BA"
            - Oak "+-BB"
            - Walnut "+-BC"
            - Cherry "+-BD"
            - Mapple "+-BE"
            - Elm "+-BF"
            - Popular "+-BG"
            - Others "+-BH"
          - Processed wood
            - Layered/jointed wood
              - Techgrain "+-BI"
              - Micro-LAM "+-BJ"
              - Others "+-BK"
            - Fibrous-felted wood "+-BL"
            - Particle product
              - Particle board "+-BM"
              - Molded wood "+-BO"
          - Cork "+-BN"
        - Textile fiber
          - Natural fiber "+-C1"
          - Man-made fiber "+-C2"
      - Amorphous
        - Plastic
          - Solid plastic
            - Clear "+-D1"
            - Smoked "+-D2"
            - Opaque "+-D3"
          - Laminate "+-D4"
        - Rubber/Elastomer
          - Natural rubber "+-E1"
          - Synthetic rubber "+-E2"
          - Elastomer "+-E3"
        - Glass
          - Commercial glass "+-G1"
          - Technical glass "+-G2"

Figure V.8 Material Sub-tree

The material code developed is also an alpha-numeric code. The first positioned letter stands for the general material family as shown in table V.2, and the second digit stands for the detailed material within a particular material family. Therefore, the material code forms a monocode structure. The relationships between the first level of materials and the detailed materials are found in the quotation marks in terminal branches in figure V.8.

5.2.5 Color Sub-tree

A sub-tree which identifies a color for a final product, especially veneer or laminate panels, has been developed and presented in figure V.9. Similar to the material tree structure, it is also a mutually exclusive path structure and two place values - a letter followed by a digit - are reserved for identification of colors. General color families and their associated codes are listed in table V.3.

The first letter of the color code identifies the color family shown above. The next digit explains the details of that chosen color family. For instance, E1 stands for the light brown. Other digits which are commonly used are 2,3 and 4 which stand for medium, dark and English, respectively.

```
                      Not specified
                      "+00"
                     :-----------------
                     :
                     :                                    Natural "+A1"
                     :                                   :-----------------
                     :                                   :                       Light "+A2"
                     :                                   :                      :-----------------
                     :                                   :  Red               1:  Medium "+A3"
                     :                                   :------------------:-----------------
                     :                                   :                    :  Dark "+-A4"
                     :                                   :                    :-----------------
                     :                            (VNR)  :
                     :            Veneer panel          1:                       Light "+A5"
                     :           :-------------------:                        :-----------------
                     :           :                   :                        :  Medium "+A6"
                     :           :                   :  Brown              1:-----------------
  Color             1:           :                   :-------------------:  Dark "+A7"
  --------CL---------:           :                   :                      :-----------------
                     :           :                   :                      :  English "+A8"
                     :           :                   :                      :-----------------
                     :           :                   :
                     :           :                   :  Others "+A9"
                     :           :                   :-----------------
                     :           :
                     :           :                      White "+B1"
                     :           :                   :-----------------
                     :           :                   :  Beige "+B2"
                     :           :                   :-----------------
                     :           :                   :                        Light "+B3"
                     :   (PANEL) :                   :                      :-----------------
                     :  Panel   1:                   :  Gray              1:  Medium "+B4"
                     :-------------------:           :-------------------:-----------------
                     :           :            (LAM)  :                      :  Dark "+B5"
                     :           :  Laminate panel  1:                      :-----------------
                     :           :-------------------:
                     :           :                   :  Black "+B6"
                     :           :                   :-----------------
                     :           :                   :  Slate "+B7"
                     :           :                   :-----------------
                     :           :                   :  Amaranto "+B8"
                     :           :                   :-----------------
                     :           :                   :  Peach "+B9"
                     :           :                   :-----------------
                     :           :                   :  Taupe "+B0"
                     :           :                   :-----------------
                     :           :
                     :           :  Fabric panel
                     :           :  "+C0"
                     :           :-----------------
                     :
                     :  Metal "+D0"
                     :-----------------

                        Not Specified
                        "+0-"
                     :-----------------
  Finish            1:  A grade "+1-"
  --------FI---------:-----------------
                     :  B grade "+2-"
                     :-----------------
```

Figure V.9 Color Sub-tree

Table V.3 COLOR FAMILIES

FAMILY	DESCRIPTION
A	Natural
B	White
C	Beige
D	Peach
E	Brown
F	Red
G	Amaranto
H	Slate
I	Gray
J	Taupe
K	Black
L	Others

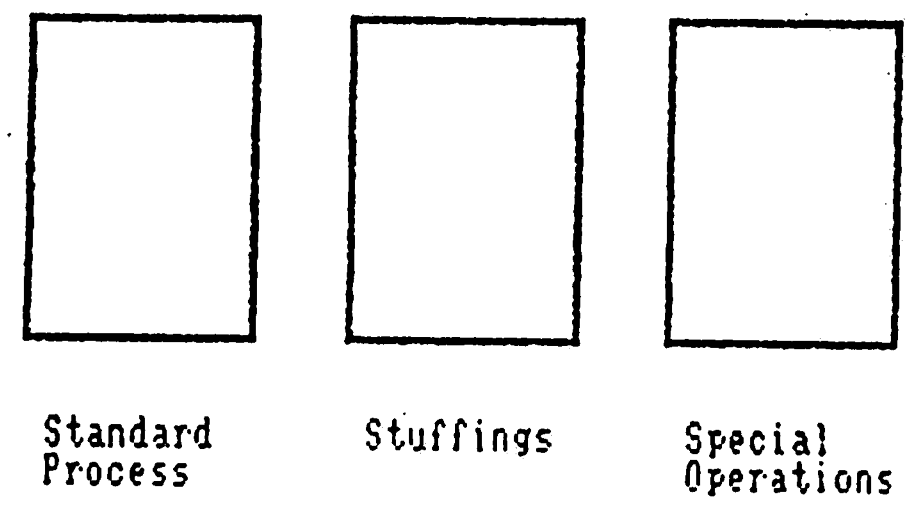
5.2.6 Process Sub-tree: Frames

According to the standard processes for frames presented in the previous chapter, a tree structure has been developed and presented in figure V.10. There are basically three branches out of the frame process sub-tree. The first branch determines a part whether it passes through standard processes. The standard processes are already stored in the computer and shown on the menu of a screen. The operator may select the standard process unless other special instructions are shown on the blue print or supplementary reference material. The next two branches determines other optional operations added to the standard processes, e.g. stuffing verticels and boring holes. Accordingly, a

```
                                               Rough
                                               cut/joint/rip/m
                                               old &
                                               plane/cut/assem
                                 Standard      ble "+1"
                                 process     1:-----------------
                              :-------------------: Non-standard
                              :                   : "+0"
                              :                   :-----------------
                              :
                              :                    Stuff verticel
                              :                    "+1"
                              :                   :-----------------
                        (FRM) : Stuffings      1: No verticel
          Frame              %:-------------------: "+0"
 --------FM---------:                             :-----------------
                              :
                              :                    Bore holes in      Vertical "+1"
                              :                    rails          1:-----------------
                              :                   :-------------------: Horizontal "+2"
                              :                   :                   :-----------------
                              :                   :
                              : Special           : Other
                              : operations     1: operation(s)
                              :-------------------: "+3"
                                                  :-----------------
                                                  : No special
                                                  : operation "+0"
                                                  :-----------------
```

Figure V.10 Process Sub-tree for frames

three digit code length is required to adequately code the process features of frames. The frame format is as follows:



5.2.7 Process Sub-tree: 5-layer Veneer Panels

Standard and special processes for fabricating 5-layer veneer panels and their related finishing operations have been previously presented. Based upon the nature of the contributions of the processes towards the final product, the processes can be divided into several functional operation segments and characterized as follows:

(1) Veneer preparation operation
(2) Press operation to form a panel
(3) Edgebanding operation
(4) Finishing operation
(5) Boring operation
(6) Special operation

Each of these functional operation segments of jobs are composed of consecutive individual operations (work elements). For example, veneer preparation operation consists of three consecutive work elements, that is, cutting veneer to length, shearing veneer to width, and splicing them. No matter what types of veneer panels are made, these three work elements are found to never change in terms of type of process or its sequence. The issue to be considered is whether the veneer preparation operation is required as a whole, as compared to the individual work element within the veneer preparation operation. Based on these functional operation segments, a tree structure for the 5-layer veneer panels has been developed and shown in figure V.11. Work elements within each of the functional elements are also shown on the terminal branches of the tree in the figure.

5.2.8 Process Sub-tree: 5-layer Laminate Panels

For the 5-layer laminate panels, the whole standard processes of laminate panels are divided into 6 functional operation segments summarized as follows:

(1) Laminate preparation operation
(2) Press panel and postforming operation
(3) Edgebanding operation

```
                                              Cut
                                              length/shear       Bookmatch "+1"
                                              width/splice      1:-----------------
                                             :-------------------:  Reverse slip
                          Prepare veneers 1:                     :  match "+2"
                         :-------------------:                   :-----------------
                         :                   :
                         :                   :  Non-standard
                         :                   :  "+0"
                         :                   :-----------------
                         :
                         :                    Press
                         :                    MDF/Timesaver/P
                         :                    ress veneer
                         :                    "+1"
                         :                   :-----------------
                         :  Press panel     1:  Non-standard
                         :-------------------:  "+0"
                         :                   :-----------------
                         :
                         :                    Trim/EB(EB,
                         :                    radius, sand)
                         :                    "+1"
                         :  Edgeband        1:-----------------
                         :-------------------:  Non-standard
                         :                   :  "+0"
                         :                   :-----------------
                         :
                         :                    Rough
                         :                    sand/spray
                         :                    edge/coat
                         :                    top-bottom/sand
                         :                    /flat
                         :                    finish/wax "+1"
                         :                   :-----------------
                   (VNR) :                   :  Hand
       Veneer panel     X:  Finishing        :  sand/stain/seco
       --------VP--------:  operation       1:  nd coat/hang
                         :-------------------:  finish "+2"
                         :                   :-----------------
                         :                   :  No finishing
                         :                   :  operation "+0"
                         :                   :-----------------
                         :
                         :                    Vertical "+1"
                         :  Boring           :-----------------
                         :  operation       1:  Horizontal "+2"
                         :-------------------:-----------------
                         :                   :  No boring
                         :                   :  operation "+0"
                         :                   :-----------------
                         :
                         :                                        Through routing
                         :                                        "+2"
                         :                                       :-----------------
                         :                                       :  Halfway routing
                         :                                       :  "+3"
                         :                                       :-----------------
                         :                                       :  Plunge routing
                         :                    Routing           1:  "+4"
                         :                   :-------------------:-----------------
                         :                   :                   :  Edge routing
                         :                   :                   :  "+5"
                         :                   :                   :-----------------
                         :                   :                   :  Combined above
                         :                   :                   :  "+8"
                         :                   :                   :-----------------
                         :  Special          :
                         :  operation       1:  Mortise/rabbet/
                         :-------------------:  dovetail/miter
                                             :  "+1"
                                             :-----------------
                                             :  Combined above
                                             :  "+9"
                                             :-----------------
                                             :  No special
                                             :  operation "+9"
                                             :-----------------
```

Figure V.11 Process Sub-tree for 5-layer Veneer Panel

(4) Finishing operation

(5) Boring operation

(6) Special operation

Based on the above functional operations, a tree structure is developed and shown in figure V.12. Work elements within each of the functional elements are also shown on the terminal branches of the tree in the figure.

5.2.9 Process Sub-tree: 3-layer Ply Panel

3-layer ply panels have seven different types of functional operation segments which are listed as follows:

(1) Preparing panel operation

(2) Edgebanding operation

(3) Part operation

(4) Finishing operation

(5) Boring operation

(6) Routing operation

(7) Special operation

3-layer panels require a hot press for veneers whareas 5-layer panels require both a hot and cold press for veneers and MDFs, respectively. The press operation is included in

```
                                    Cut lam./cut
                                    backer "+1"
                Prepare            :-----------------
                laminates        1: No-preparation
           :-------------------:    "+0"
           :                       :-----------------
           :
           :                        Cold press
           :                        MDF/timesaver/p
           :                        ostform "+1"
           : Press/postform  1:-----------------
           :-------------------:  Non-standard
           :                   :  "+0"
           :                   :-----------------
           :
           :                        Cut/edgeband
           :                        "+1"
           :                       :-----------------
           : Edgeband        1: Non-standard
           :-------------------:  "+0"
           :                   :-----------------
           :
           :                        Rough
           :                        sand/spray
           :                        edge/coat
           :                        top-bottom/sand
           :                        /flat
           :                        finish/wax "+1"
           :                       :-----------------
           :                       : Spray laminate
           :                       : & bareboard
           :                       : "+2"
           : Finishing             :-----------------
           : operation         1: Hand out excess
           :-------------------: plastics
     (LAM) :                   : (cleaning
Laminate panel %:              : edges) "+3"
--------LP---------:           :-----------------
           :                   : No finishing
           :                   : operation "+0"
           :                   :-----------------
           :
           :                    Vertical "+1"
           :                   :-----------------
           :                   : Horizontal "+2"
           : Boring            :-----------------
           : operation       1: Combined above
           :-------------------:  "+3"
           :                   :-----------------
           :                   : No boring
           :                   : operation "+0"
           :                   :-----------------
           :
           :                                    Through routing
           :                                    "+2"
           :                                   :-----------------
           :                                   : Halfway routing
           :                                   : "+3"
           :                                   :-----------------
           :                                   : Plunge routing
           :                    Routing      1: "+4"
           :                   :-----------------:-----------------
           :                   :               : Edge routing
           :                   :               : "+5"
           :                   :               :-----------------
           :                   :               : Combined above
           :                   :               : "+8"
           : Special           :               :-----------------
           : operation(s)     1:
           :-------------------: Mortise/rabbet/
                               : dovetail/miter
                               : "+1"
                               :-----------------
                               : Combined above
                               : "+9"
                               :-----------------
                               : No special
                               : operation "+0"
                               :-----------------
```

Figure V.12 Process Sub-tree for 5-layer Laminate Panel the veneer preparation operation which then becomes a panel preparation operation. Compared with 5-layer ply panels, two new operations are added to the 3-layer ply panels, namely part operation and routing operation. Many of the 3-ply panels have smaller dimensions than the 5-ply panels. Because the 3-ply panes are mainly used as components for cases such as doors, side walls and drawers, routing operations are frequently required for hinges or door locks. Unlike the 5-ply panels, routing operations for 3-ply panels are considered as independent standard operation. All the above functional operations and their related work elements are shown in the tree structure in figure V.13.

5.2 Source File Development with DCLASS

Once a tree structure has been developed, the tree sketch is converted into a DCLASS source file. The source file defines the structure, content, and the processing of the tree. Brigham Young University provides and interactive "tree building system" software pachage, called SPROUT, which was used in this thesis. The SPROUT pachage allows first time input of tree data, in an interactive situation, directly from a tree diagram and automatically generates the tree source file. Source files for the new GT classification coding system are attached in Appendix A.10. A

```
                                          Cut
                                          length/shear
                                          width/splice/ho
                                          t press "+1"
                                         :-----------------
                       Prepare panel    1:  Non-standard
                      :-----------------:   "+0"
                      :                  :-----------------
                      :
                      :                   Cut EB/Edgeband
                      :                   "+1"
                      :                  :-----------------
                      : Edgeband        1: Non-standard
                      :-----------------:  "+0"
                      :                  :-----------------
                      :
                      :                   Part "+1"
                      : Part panel      1:-----------------
                      :-----------------:  No part "+0"
                      :                  :-----------------
                      :
                      :                   Sand
                      :                   faces/edges/pul
                      : Finishing         ls "+1"
                      : operation       1:-----------------
                      :-----------------:  No sanding
                      :                  : operation "+0"
                      :                  :-----------------
                      :
                      :                   Vertical "+1"
                      :                  :-----------------
                      :                  : Horizontal "+2"
                      : Boring           :-----------------
                (3LY) : operation       1: Both vertical
   3-layer ply        :-----------------:  and horizontal
   panel            %:                   : "+9"
   --------TP---------:                  :-----------------
                      :                  : No boring
                      :                  : operation "+0"
                      :                  :-----------------
                      :
                      :                   Through routing
                      :                   "+1"
                      :                  :-----------------
                      :                  : Halfway routing
                      :                  : "+2"
                      :                  :-----------------
                      :                  : Plunge routing
                      :                  : "+3"
                      : Routing          :-----------------
                      : operation       1: Edge routing
                      :-----------------:  "+4"
                      :                  :-----------------
                      :                  : Combined above
                      :                  : "+9"
                      :                  :-----------------
                      :                  : No routing
                      :                  : operation "+0"
                      :                  :-----------------
                      :
                      :                   Mortise/rabbet/
                      :                   dovetail/miter
                      :                   "+1"
                      :                  :-----------------
                      : Special          : Glue pulls "+2"
                      : operation(s)    1:-----------------
                      :-----------------:  Both "+9"
                                         :-----------------
                                         : No special
                                         : operation "+0"
                                         :-----------------
```

Figure V.13 Process Sub-tree for 3-layer Ply Panel test run of the tree and its resulting GT code are also attached in Appendix A.11.

VI. CAPP System Interface

We previously discussed in chapter 1 the situation for a feasible variant CAPP system. The ideal situation for a variant CAPP system is once again summarized as follows:

The variant CAPP system will be feasible when

1) the product design is fairly stable.
2) lot size is medium-high.
3) parts within a family are of similar size.
4) material type is the same for all members of the family.
5) few engineering changes are normally made.

In the case of 5- and 3-ply panels in the case company, the above conditions seem to be fairly well met. The basic panel designs are relatively simple and do not exhibit much variation. These panels are widely used key components for various products, such that the lot size is also high and stable. Woods are also the dominant material throughout the various panels. Unlike the metal working industry, different type of woods usually do not have an influence on the process. Different types of woods do influence the quality of the product and the price. Based on such observations, it is concluded that a variant CAPP system seems suitable for the panel product line of the case company.

In developing tree and code structures for the process of each type of panels in the previous chapter, the total process of a particular type of panel was broken down into several functional operation segments. Each segment contributed progress towards a final product. The following rules may be followed in segmenting the processes.

1) Each of the segments should have a functional operation which make it distinctive from other segments.
2) The sequence and type of machining processes within a segment should be preferably fixed.
3) The sequence of the whole segments preferably follows the flow of the original process routine.

A 5-layer veneer panel, for example, usually requires about 20 different types of machining processes. By thoroughly examining the processes, 6 different type of operation groups (segments) are formed, namely veneer preparation operation, press operation, edgebanding operation, finishing operation, boring operation, and finally, special operation. Each of these 6 segments has its own operational characteristics which makes it distinctive from other segments in terms of the nature of operations.

One of the most important things to be kept in mind in this functional operation segment(FOS) method is that there should be reasonably fixed machining processes within each of these functional operation segments in terms of both sequence and type of processes. In the case of a 5-layer veneer panel, the press operation has three different machining processes within itself, namely pressing MDF to a frame, sanding it through Timesaver machine, and finally pressing veneers to MDFs. According to the route sheet analysis in chapter IV, 99 percent of the 5-layer veneer panels would follow this machining sequence in terms of the pressing operation. Therefore, the pressing operation can be considered as one type of machining process and can be reflected on the GT code in that way.

By conducting the FOS method, virtually all of the processes performed to one part can be packed into several types of functional operations and then reflected on the process section of a GT code which has a rather limited number of digits. For example, a GT code with 10 different functional operation segments each of which has 4 machining process elements within itself, has a total of 40 different machining processes. This can be reflected with a 10-digit process code by assigning 1 digit of code to each of the functional operation segments. Optional processes or variations of the standard processes are also capable of being developed within the tree structure logic. Therefore, the resulting code will contain virtually all of the processes, either standard or special, performed on a particular part.

According to the survey conducted by the prof. V. R. Malacic [46], there are basically six types of knowledge bases required for a CAPP expert system. These knowledge bases are briefly summarized as follows:

(1) <u>Knowledge base for workpiece:</u> This knowledge base can be divided into common and specific workpiece knowledge. Common knowledge covers the main characteristics about the workpiece. Specific knowledge concerns the functional, geometrical, and technological aspects of the workpiece or product.

(2) <u>Knowledge base for type forms:</u> A type form is a set of elementary forms which can be any form that appears in any state of transformation, from the primitive form to the final type form.

(3) <u>Knowledge base for type technological sequences:</u> The manufacturing integral concept is based on the principle of the type forms mentioned above, combined with a technological sequences. This knowledge base controls the manufacturing sequences by mapping each of the technological transformation process into one type form or into several type forms. In other words, the technological sequence knowledge base controls the manufacturing sequences by matching with the transformation of the part or product.

(4) <u>Knowledge base for tools:</u> Knowledge base for tools is basically systematized through detailed catalogues. This knowledge base covers technological aspects of the tools, such as machining types, cutting conditions, tool wear due to cutting, and so on.

(5) <u>Knowledge base for machine tools:</u> Knowledge base for machine tools can be also systematized through the detailed catalogues. This knowledge base mainly covers both technological aspects of the machine tools and their related factors, such as machine tool types and the type of operation, capabilities and

capacities, set-up times, cost estimations, and required man powers.

(6) Knowledge base for fixtures: There may be two parts of knowledge bases for fixtures. One part of the knowledge base corresponds to the fixture-workpiece location and clamping, whereas the second part of the knowledge base deals with the interface between the fixture and machine tool for a given set of operations.

The process aspects of the proposed GT code developed by the Functional Operation Segment (FOS) method, along with design aspects, provides information directly related to the first four of the knowledge bases mentioned above. The relationship between the proposed GT code and the above four knowledge base for CAPP can be schematically illustrated in figure VI.1.

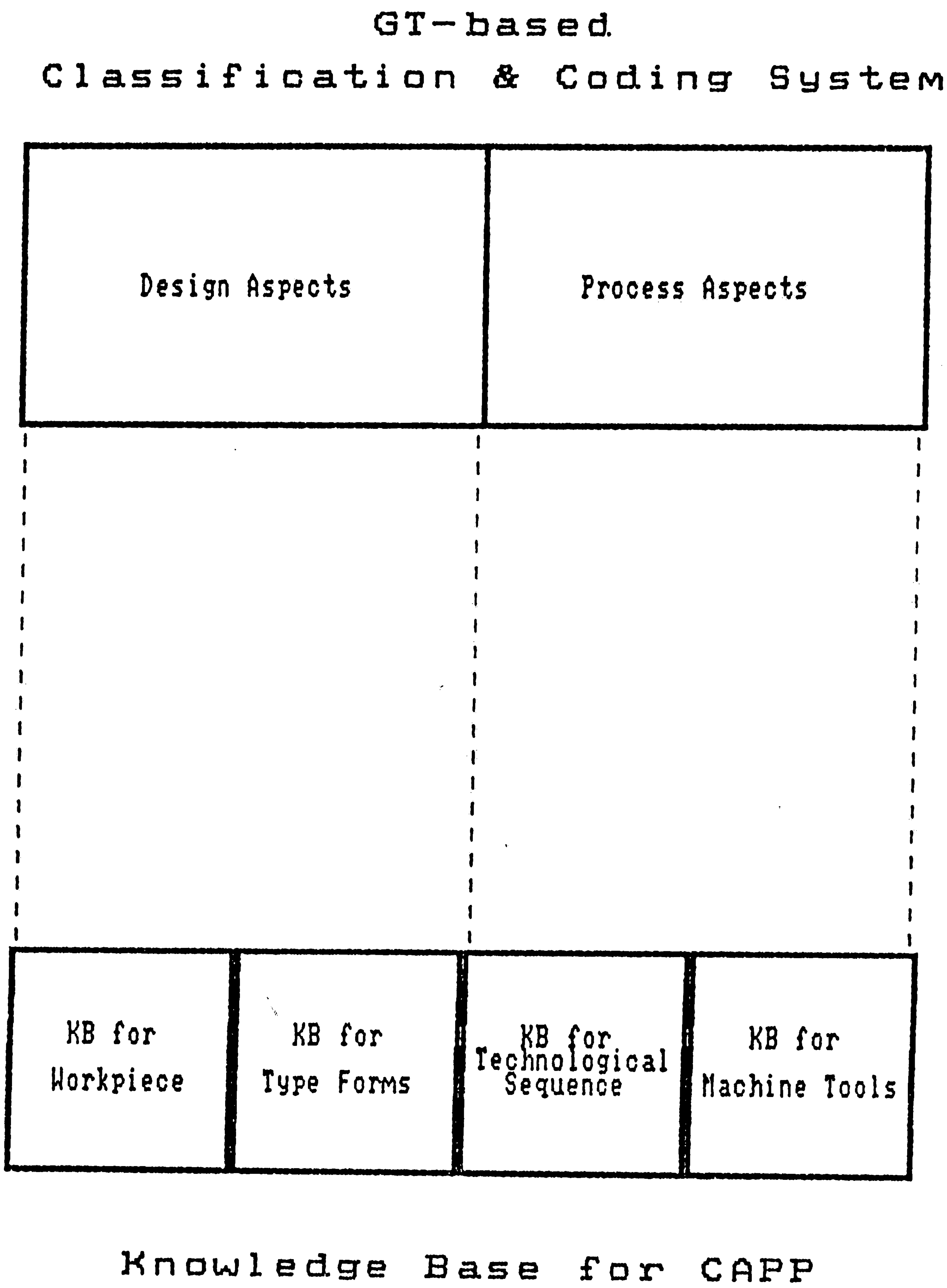


Figure VI.1 Interface between Classification and Coding System and Knowledge Base for CAPP

VII. Conclusions

The majority of the developed and marketed GT-based classification and coding systems are mainly based on the metal-working industry. Unfortunately, a system based on the metal-working industry is not always quite suitable to a non-metal working industries, particularly the furniture industry investigated in this thesis. The essence of the difference in nature can be stated in two different ways, i.e., from the design point of view and the process point of view.

The design features of the basic components in the furniture industry are relatively simple compared with those of the metal working industry. There are less variations in designs and typically only one kind of material is dominantly used - the woods which have properties which are relatively simple compared to metals. On the other hand, there are other features not usually found or of less importance in the metal-working industry that should be reflected in a code. Some of those features include the hierarchical level of products, function of the products, and the identification of designers.

There are also distinguishable differences in the way that a part is processed when comparing the furniture and metal-working industry. The major flow of the process of the furniture industry is assembly process oriented, while the dominant processes in the metal-working industry are cutting operations. Also of note is that the nature of the process is relatively simple and less process parameters are of concern in the furniture industry. This is partly due to the simplicity of the material properties.

To successfully implement group technology in the furniture industry there is a strong need to develop a new classification and coding system which is particularly suitable to that industry. Due to the relative simplicity in the nature of both design and processes for the cases investigated, it is more feasible for the classification and coding system to carry both design and manufacturing features to meet various departments' needs.

Route sheet analysis (RSA) and production flow analysis (PFA) provide helpful information to identify process features, especially standard and special operations required for a particular part. RSA method is relatively simple and can be conducted manually without difficulty. RSA can also easily define the bottle neck machines. However, it is hard to obtain mutually exclusive groups by the RSA method alone. PFA method is somewhat complicated and it is difficult to define bottle neck machines. Even though PFA can be done manually, it is very helpful to make use of a computer. PFA and RSA are complementary each other.

Because of the simplicity and minimal variation in both the designs and processes inherent to the furnitures industry, a variant CAPP system seems reasonably suitable to that industry.

The functional operation segments (FOS) method overcomes the shortcomings of a variant CAPP system discussed in section 3.2.2 - the inflexibility. The FOS method can pack numbers of processes into a code with a limited number of digits. A process code generated by the FOS method has options to code either standard or special processes required for a particular part, while providing somewhat sequential orders of a process. In other words, the resulting code might include virtually all the processes concerned with a particular part.

The proposed GT code developed in this thesis carries comprehensive information about the process features of a part as well as design features. It was determined that the proposed code can serve as a front-end to a CAPP system. The proposed code can be input to the knowledge base of a CAPP system, and the rules of a CAPP system can be executed when the conditions match with the facts in the knowledge base.

VIII. Recommendations for Future Research

A GT-based classification and coding system implemented with the DCLASS system has been developed and contributions to a knowledge based CAPP expert system have been discussed. An extension of this research will be devoted to develop an CAPP expert system based on the proposed, GT-based classification and coding system. To facilitate this, it is recommended that the following subject matter be considered initially:

1) Determination of a knowledge representation method.
2) Determination of the scope of the knowledge base.
3) Determination of the scope of products to be included in a CAPP system.

Domain knowledge can be represented basically by one of two methods: 1) by the logic incorporated within the tree structure of DCLASS, or 2) by a programming language. The domain knowledge could possibly be represented as an 'if-then' structure in decision trees. The DCLASS software may then process these trees to obtain a final solution. However, due to the tremendous volume of knowledge required to build an CAPP system, the resulting tree structure might be immense and the work would be frustrating.

Programming languages for representing the knowledge of an expert system can be divided into two categories: (1) a programming language used for expert system development, or (2) a knowledge engineering language expressly designed for expert system development. Knowledge engineering languages are part of programming languages, but they are expressly designed for constructing and debugging expert system. Unlike the programming language, the tailoring is already done in the knowledge engineering languages, which often sacrifices flexibility in terms of how knowledge is represented and manipulated. The other difficulty in representing by a knowledge engineering languages is in finding a suitable language to the problem among the available languages.

A interface between the developed classification and coding structure and the knowledge base of a CAPP expert system was discussed in chapter VI. Currently, the proposed GT code supports the 4 types of knowledge bases among the 6 types required for building the complete knowledge base for CAPP system. As a starting point, these 4 types of knowledge bases (knowledge bases for workpieces, type forms, type technological sequences, and machine tools) need to be further researched and developed. After the 4 knowledge bases are successfully developed, the other two knowledge bases (knowledge bases for tools and fixtures) should be investigated and developed.

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X. Appendices

Appendix A.1 PACK LIST
- A group of parts with identical process routings

Pack ID	QTY	Description
A1	3	frame
A2	22	frame
A3	1	frame
A4	1	frame
A5	1	frame w/verticel
A6	1	frame
A7	3	m/frame
A8	13	m/frame
A9	1	frame w/4x4 block
B1	5	SHLF CLST
B2	32	TOP WKSF SHLF
B3	2	TOP WKSF
B4	6	M/PNL TOP(VDU)
C1	7	TOP SYS, HGT
C2	2	SHLF BOOKCASE
C3	2	SHLF CLST
D1	1	WKSF
D2	7	WKSF TOP
D3	2	SHLF CLST
D4	1	WKSF
D5	1	TOP SYS, HGT
D6	7	WKSF TOP M/PNL
D7	14	TOP WKSF
D8	3	TOP
D9	1	M/PNL VDU CORNER
D10	3	TOP
D11	1	LEG
D12	1	WKSF
D13	1	SHLF CLST
D14	1	SHLF
D15	1	SHLF CLST
D16	2	SHLF
D17	1	WKSF
E1	3	PNLS, TOP/BOTTOM CLST

F1	23	TOP WKSF
F2	2	SHLF
F3	2	TOP CLST, BOTTOM CLST
F4	2	TOP CLST, BOTTOM CLST
F5	1	WKSF
G1	1	WKSF
H1	1	FRM W/4X4 BLOCK
H2	3	FRM
H3	8	FRM
I1	9	MDF, CHIPCORE, FIBERBOARD
I2	1	CHIPCORE WKSF
J1	1	PNL, WKSF

Appendix A.2 Combined Pack List

- A group of parts which need the same machining processes regardless of the sequence of machining processes and the number of times processed through a particular machine

Pack ID	QTY	Component packs	Description
1	38	A1,A2,A8	frame
2	6	A4,A5,A6,A7	frame
3	1	A3	frame
4	1	A9	frame
5	38	B2,B4	finishing pnl
6	2	B3	finishing pnl
7	5	B1	finishing pnl
8	7	C1	laminate pnl
9	4	C2,C3	laminate pnl
10	35	D1,D2,D6,D7,D8,D10	veneer pnl
11	3	D3,D15	veneer pnl
12	3	D14,D16	veneer pnl
13	1	D12	veneer pnl
14	1	D5	veneer pnl
15	1	D4	veneer pnl
16	1	D13	veneer pnl
17	1	D9	veneer pnl
18	1	D11	veneer pnl
19	1	D17	veneer pnl
20	23	F1	laminate pnl
21	4	F3,F4	laminate pnl
22	2	F2	laminate pnl
23	1	F5	laminate pnl
24	1	G1	finishing pnl
25	1	H1	frame
26	3	H2	frame
27	8	H3	frame
28	1	J1	finishing pnl
29	9	I1	MDF, chipcore
30	1	I2	MDF, chipcore
31	3	E1	assembly

Appendix A.3 Machine Code Conversion Table

M/T code	Description	Conversion #1 (including spcl process)	Conversion #2 (excluding spcl process)
001	Porter crosscut saw	1	1
002	Mattison rip saw	2	*
003	Bauerle jointer	3	2
007	Tannewitz table saw	4	*
008	Timesaver	5	3
009	Midwest postformer	6	*
012	Tannewitz table saw	7	*
017	Bacci mortise machine	8	*
019	Root horz. boring machine	9	*
020	Root vert. boring machine	10	*
027	Bauerle shaper	11	*
028	Stemac sander	12	4
029	Edge spray booth	13	5
030	UV finishing line	14	6
031	Flat finishing line	15	7
032	Bell machine	16	*
034	Wax line	17	8
035	Postform lam. saw	18	9
036	Mattison stroke sander	19	*
038	Postform spray booth	20	*
039	Stain line	21	*
045	Mattison edge sander	22	*
056	Olimpic double edgebander	23	*
058	Homag tenoner/edgebander	24	10
075	B&G crosscut saw	25	11
076	Rockwell table saw	26	12
077	Postform lam. index & pinch	27	*
078	Kuper veneer splicer	28	13
080	Albertic CNC boring mach.	29	14
081	Homag postformer	30	15
103	Homag tenoner/edgebander	31	16
119	Jenkins tenoner	32	17
198	Bauerle veneer guillotine	33	18
224	SCM gang rip saw	34	19
286	Zapf & L/S K/D benches	35	*
297	Wemhoner auto flat press	36	20
298	Typer cold press	37	21
299	Torwegge tenoner/edgebander	38	*

300	Heeseman auto sander	39	22
301	Flat finishing line	40	*
302	Weeke boring machine	41	*
322	Weinig planner/molder	42	23
324	Sheer table saw	43	*
340	Paint line wood	44	*
905	Bench, wood sand & prep.	45	*
908	Bench, woodshop machine	46	*
910	Bench, woodshop, sub-assy.	47	24
916	Bench, hand	48	25
917	Bench, hand boring	49	*

Appendix A.4 Distribution of Machine Frequencies
- How many times a machine is used among the samples.

M/T #	Description	Frequency	
286	Zapf & L/S K/D benches	6	*
002	Mattison rip saw	1	*
032	Bell machine	8	*
301	Flat finishing line	1	*
905	Bench, wood sand & prep.	2	*
340	Paint line wood	7	*
003	Bauerle jointer	46	
224	SCM Gang rip saw	120	
001	Porter crosscut saw	50	
119	Jenkins tenoner	132	
322	Weinig planner/molder	139	
910	Bench, woodshop, sub-assy	65	
039	Stain line	2	*
030	UV finishing line	40	
031	Flat finishing line	45	
028	Stemac sander	58	
029	Edge spray booth	45	
300	Heeseman auto sander	46	
324	Sheer table saw	10	*
009	Midwest postformer	1	*
038	Postform spray booth	2	*
045	Mattison edge sander	1	*
077	Postform lam. index & pinch	2	*
007	Tannewitz table saw	12	*
036	Mattison stroke sander	1	*
299	Torwegge tanoner/edgebander	1	*
017	Bacci mortise machine	1	*
019	Root horz. boring machine	1	*
027	Bauerle shaper	5	*
020	Root vert. boring machine	12	*
056	Olimpic double edgebander	2	*
012	Tannewitz table saw	2	*
908	Bench, woodshop machine	3	*
080	Albertic CNC boring	70	
078	Kuper veneer splicer	68	
034	Wax line	40	
035	Postform laminate saw	41	
081	Homag postformer	40	
076	Rockwell table saw	45	

103	Homag tenoner/edgebander	41	
916	Bench, hand	41	
298	Typer cold presser	71	
008	Timesaver	70	
917	Bench, hand boring	1	*
075	B & G crosscut saw	96	
198	Bauerle veneer guillotine	90	
297	Wemhoner auto flat press	49	
302	Weeke boring machine	23	*
058	Homag tenoner/edgebander	137	

Appendix A.5 Standard and Special processes of the 5-layer ply panel

1) Std processes of frames

M/T #	Description	f
001	cut (4) pieces to rough length	50
003	joint	46
224	rip (2) rails to width	120
224	rip (2) rails to width	120
322	plane/mold (2) long rails	139
322	plane/mold (2) short rails	139
119	cut (2) rails	132
910	assemble frame/stuff verticel	65

Special processes of frames

007	cut rails	12
032	cut rails	8
020	bore holes in rails	12
002	rip	1

2) Std processes of veneer panels

075	cut face(A-grade) veneer to length	96
198	shear face veneer to width	90
078	splice	68
075	cut back(B-grade) veneer to length	96
198	shear back veneer to width	90
078	splice	68
298	press blank panel	71
008	sand blank panel	70
297	press panel	49
075	trim EB length	96
058	cut to width and edgeband	137
058	cut to length and edgeband	137
080	bore for holes, wire holes, grommets	70

Special processes of veneer panels

302	bore for holes, wire holes, grommets	23
020	bore for holes, wire holes, grommets	12
017	slot	1
027	slot	5
019	bore holes	1
917	bore holes	1
012	cut angle	2
056	edge	2
908	hand trim angled edge	3
299	trim, EB, radius sand	1
036	sand 2 sides	1

3) Std processes of laminate panels

298	press MDF (chipcore) to frame	71
008	sand blank	70
058	cut to width and radius	137
035	cut laminate	41
076	cut backer	45
081	postform	40
103	cut to length and EB	41
080	bore holes, wire holes, grommets	70
916	clean & file	41

Special processes of laminate panels

302	bore holes, wore holes, grommets	23
020	bore boles, wire holes, grommets	12
038	spray laminate & bareboard	2
077	attach laminate, pinchroll & attach fixture	2
009	preheat, postform & remove fixture	1
908	hand rout excess plastic	3
045	edge sand	1

4) Std processes of finishing panels

028	sand	51
029	spray edge	45
030	coat underside	40
300	sand (A twice, B once)	46
031	flat finish	45
034	wax	40

Special processes of finishing panels

905	hand sand	2
039	stain	2
301	finish second coat	1
340	hang, finish, wax	7

Appendix A.6 Pack Lists of Panel-making Process

Pack ID	QTY	Description/ Comment	Machines used
1	47	3-ply panel/ Both front and back veneers are different materials	075, 078, 198, 297
2	66	3-ply panel/ Both front and back veneers are same materials	075, 078, 198, 297
3	7	No splicing	075, 078, 297
4	3	Special processes	075, 078, 198, 297, 008
5	2	Special processes	075, 078, 198, 297, 008, 298
6	1	Special processes	075, 078, 198, 297, 298
7	1	Special processes	075, 198, 297, 324
8	1	Special processes	075, 078, 198, 297, 010
9	1	Special processes	075, 078, 198,

Appendix A.7 Pack List of Component-making Process

Pack ID	QTY	Machines Used
1	6	----
2	3	007
3	1	007, 012, 019, 020, 323
4	3	007, 012, 020, 045*
5	2	007, 012, 020, 045, 323
6	2	007, 012, 020, 323
7	13	007, 012, 026
8	1	007, 012, 045
9	4	007, 019, 020, 045, 323
10	6	007, 020
11	1	007, 020, 036
12	3	007, 020, 323
13	2	007, 020, 908
14	1	007, 036
15	1	010, 012, 045, 302, 323
16	1	010, 020, 066, 302, 323
17	10	012
18	2	012, 020
19	1	012, 020, 026, 202, 297
20	1	012, 020, 026, 202, 297, 300, 302
21	1	012, 020, 026, 297
22	1	012, 020, 026, 323, 908
23	1	012, 020, 045
24	9	012, 020, 202
25	2	012, 020, 202, 297, 323
26	1	012, 026, 202, 297, 302
27	1	012, 035, 067, 091, 297, 908, 914
28	31	012, 067, 086, 091, 093, 300, 914
29	4	012, 067, 091, 093, 300, 914
30	1	012, 202
31	1	012, 300
32	8	019, 020
33	2	019, 020, 045, 302, 323
34	5	019, 020, 323
35	2	019, 036, 040, 045, 323, 339
36	3	019, 045, 302, 323
37	2	019, 302
38	2	019, 302, 323
39	4	019, 323
40	31	020

41	1	020, 026
42	1	020, 035, 297, 909
43	12	020, 323
44	1	020, 323, 907
45	1	020, 323, 908
46	2	020, 908
47	5	033, 045, 084, 091, 093, 300
48	2	323
49	1	907
50	1	007, 010, 302, 323
51	1	010, 302
52	1	----
53	1	001, 002, 003, 012, 020, 027, 036, 322, 908
54	1	007
55	1	007, 010, 020, 302
56	1	007, 020, 323
57	1	011, 020, 027, 045, 908
58	1	012, 067, 086, 091, 093, 300, 914
59	1	012, 302
60	1	019
61	1	020
62	1	020, 027
63	1	300, 339, 340
64	1	010, 017, 019
65	1	019, 323
66	1	020
67	2	908
68	1	020, 908
69	1	302
Total	223	

- Pack 1 through 49 include 057, 056 as common machines.
- Pack 50 and 51 include 056 as a common machine.
- Pack 52 through 63 include 057 as a common machine.
- Pack 64 through 67 include 058 as a common machine.
- Pack 68 and 69 include 057, 058 as common machines.

Appendix A.8 Revised Pack List of Component-making Process

Pack ID	Element Pack	QTY	Machines Used
1	1, 49	7	----
2	2, 14	4	007
3	7, 8	14	007, 012
4	3	1	007, 012, 019, 020, 323
5	4	3	007, 012, 020
6	5, 6	4	007, 012, 020, 323
7	9	4	007, 019, 020, 323
8	10, 11, 13	9	007, 020
9	12	3	007, 020, 323
10	17, 26, 30	11	012
11	18, 19, 21, 23, 24	14	012, 020
12	20	1	012, 020, 300
13	22, 25	3	012, 020, 323
14	27	1	012, 067, 091, 914
15	28	31	012, 067, 086, 091, 093, 300, 914
16	29	4	012, 067, 091, 093, 300, 914
17	31	1	012, 300
18	15	1	012, 323
19	37	2	019
20	32	8	019, 020
21	33, 34	7	019, 020, 323
22	35, 36, 38, 39	11	019, 323
23	40, 41, 42, 46	35	020
24	16, 43, 44, 45	15	020, 323
25	47	5	091, 093, 300
26	48	2	323
27	51	1	----
28	50	1	007, 323
29	52	1	----
30	54	1	007
31	55	1	007, 020
32	56	1	007, 020, 323
33	59	1	012
34	53	1	012, 020
35	58	1	012, 067, 086, 091, 093, 300, 914

36	60	1	019
37	57, 61, 62	3	020
38	63	1	300
39	67	2	----
40	64	1	019
41	65	1	323
42	66	1	020
43	69	1	----
44	68	1	020

- Pack 1 through 26 include 057, 056 as common machines.
- Pack 27 and 28 include 056 as a common machine.
- Pack 29 through 38 include 057 as a common machine.
- Pack 39 through 42 include 058 as a common machine.
- Pack 43 and 44 include 057, 058 as common machines.

Appendix A.9

```
program pfa(input);
type
  matrix=packed array[1..200,1..200] of boolean;
  side=packed array[1..200] of integer;

var
  mat:matrix;
  row,col:side;
  i,j,x,y:integer;
  infile:text;
  name:string[10];

procedure init;
var i,j:integer;
 begin
   name:='          ';
   writeln('Please input the name of your file which contains the data');
   read(trm,name);
   assign(infile,name);
   reset(infile);
   for i:=1 to 200 do
    for j:=1 to 200 do
     mat[i,j]:=false;
   for i:=1 to 200 do
    begin
     row[i]:=i;
     col[i]:=i;
    end
end;

procedure givedata;
var i,j,k,t:integer;
 begin
  writeln('Please input the value of row and column');
  read(trm,x);
  read(trm,y);
  i:=1;
 while not eof(infile) do
  begin
   while not eoln(infile) do
    begin
     read(infile,t);
     mat[i,t]:=true;
    end;
    readln(infile);
   i:=i+1;
   end;
end;


procedure printoutdata;
var i,j:integer;
 begin
 writeln(lst,'Following is the input data');
 writeln(lst);writeln(lst);
```

```
 write(lst,' ':2);
 for i:=1 to x do
    write(lst,i:2);
 writeln(lst);
 for i:=1 to y do
   begin
    write(lst,i:2);
    for j:=1 to x do
     if mat[i,j] then write(lst,'1':2)
                 else write(lst,' ':2);
     writeln(lst);
   end
end;


function rbinum(n:integer):real;
var i:integer;
    s:real;
 begin
  s:=0;
  for i:=1 to x do
    if mat[n,i]then
     s:=s+exp((x-i)*ln(2));
  rbinum:=s;
end;

function cbinum(n:integer):real;
var i:integer;
    s:real;
 begin
  s:=0;
  for i:=1 to y do
   if mat[i,n] then
    s:=s+exp((y-i)*ln(2));
 cbinum:=s;
end;

procedure sort_col;
 var i,j,k,t:integer;
     temp:array[1..200] of boolean;
 begin
  for i:=1 to 200 do
   temp[i]:=false;

 for i:=1 to y do
  for j:=i to y do
    if rbinum(i)<rbinum(j) then
     begin
      for k:=1 to x do
       temp[k]:=mat[i,k];
      for k:=1 to x do
       mat[i,k]:=mat[j,k];
      for k:=1 to x do
       mat[j,k]:=temp[k];
      t:=col[i];
```

```
        col[i]:=col[j];
        col[j]:=t;
       end
 end;

 procedure sort_row;
  var i,j,k,t:integer;
      temp:array[1..200] of boolean;
  begin
   for i:=1 to 200 do
    temp[i]:=false;

   for i:=1 to x do
    for j:=i+1 to x do
     if cbinum(i)<cbinum(j) then
      begin
       for k:=1 to y do
        temp[k]:=mat[k,i];
       for k:=1 to y do
        mat[k,i]:=mat[k,j];
       for k:=1 to y do
        mat[k,j]:=temp[k];
       t:=row[i];
       row[i]:=row[j];
       row[j]:=t;
      end
end;

function comp(p,q:side):boolean;
var i:integer;
    t:boolean;
begin
 t:=true;
 for i:=1 to 200 do
  if p[i]<>q[i] then t:=false;
 comp:=t;
end;


procedure sort_matrix;
var
  t1,t2:side;
  i:integer;
 begin
  repeat
   t1:=col;
   t2:=row;
   sort_col;
   sort_row;
   for i:=1 to 10 do
    write(t2[i]);
   writeln;
   for i:=1 to 10 do
    write(row[i]);
```

```
    writeln;
    writeln(comp(t2,row));
  until comp(t1,col) and comp(t2,row);
end;



begin
 init;
 givedata;
 printoutdata;
 sort_matrix;
 writeln(lst);writeln(lst);
 writeln(lst,'Following is the output of your data.');
 writeln(lst);
 write(lst,' ':2);
 for i:=1 to x do
 write(lst,row[i]:2);
 writeln(lst);
 for i:=1 to y do
  begin
  write(lst,col[i]:2);
  for j:=1 to x do
    if mat[i,j] then
      write(lst,'1':2)
    else write(lst,' ':2);
   writeln(lst);
   end

end.
```

Appendix A.10

a

```
C:\DCLASS>type partc0.src
;;SUBTREE GT MAIN PART CLASSIFICATION
;;//
;;//
;;//
;;//
;;TREE
PARTCL.1.2      4  FUNCTI.2        DIMENS.3.11     MATERI.4        PROCES.5
FUNCTI.2.2      2  FAMILY.6        PRODUC.7.12
FAMILY.6.1      4  GENERA.8        DESIGN.9        SEATIN.10       DESKST.11
DESIGN.9.1      4  MORRIS.12       ZAPF.13         NEWHAN.14       STEPHE.15
SEATIN.10.1     3  OFFICE.16       SIDECH.17       LOUNGE.18
DESKST.11.1     2  DESKCR.19       TABLE.20
MATERI.4.2      3  MATERA.21.13    COLOR.22.14     FINISH.23.15
PROCES.5.1      4  FRAME.24.16     VENEER.25.17    LAMINA.26.18    N3LAYE.27.19
;;CALLED SUBTREES
11  DM
12  LF
13  MA
14  CL
15  FI
16  FM
17  VP
18  LP
19  TP
;;TEXT
1   Part classification
2   Functional spec.
3   Dimension
4   Material/Color/Finish
5   Process selection
6   Family selection
7   Production level & function
8   General
9   Designer's system
10  Seatings
11  Desks & Tables
12  Morrison
13  Zapf
14  New Hannah
15  Stephens
16  Office seating
17  Side chair
18  Lounge seating
19  Desk/Credenzas
20  Table
21  Material
22  Color
23  Finish
24  Frame
25  Veneer panel
26  Laminate panel
27  3-layer ply panel
;;INPUT KEYS
FRAME    **  FRM
VENEER   **  VNR
LAMINA   **  LAM
N3LAYE   **  3LY
;;OUTPUT KEYS
MORRIS   **  MO 4
ZAPF     **  ZF 4
NEWHAN   **  NH 4
```

```
STEPHE   **   ST 4
;;CODE
GENERA   GE
MORRIS   MO
ZAPF     ZF
NEWHAN   NH
STEPHE   ST
OFFICE   OS
SIDECH   SC
LOUNGE   LS
DESKCR   DC
TABLE    TB
;;END

C:\DCLASS>
```

```
type partc2.src
;;SUBTREE LF
;;//
;;// by H. Kim
;;// Aug. 15 1986
;;//
;;//
;;TREE
PRODUC.1.1      5  GROUPI.2     ASSEMB.3     SUBASS.4     COMPON.5
                   RAWMAT.6
SUBASS.4.1      3  PANEL.7      WORKSU.8     OVERHE.9
PANEL.7.1       4  VERTIC.10    KNEEHO.11    CURVED.12    LANKIT.13
WORKSU.8.1      5  WORKSA.14    VDTSUR.15    EXTENS.16    BRIDGE.17
                   PRINTE.18
COMPON.5.1      6  FRAME.19     VENEER.20    LAMINA.21    N3LAYE.22
                   EDGEBA.23    INSERT.24
;;TEXT
1    Production level & function
2    Grouping
3    Assembly
4    Subassembly
5    Component
6    Raw material
7    Panel
8    Worksurface
9    Overhead shelf
10   Vertical panel
11   Kneehole panel
12   Curved panel
13   LAN kit panel
14   Worksurface
15   VDT surface
16   Extension surface
17   Bridge surface
18   Printer surface
19   Frame
20   Veneer
21   Laminate
22   3-layer ply panel
23   Edgeband
24   Insert
;;OUTPUT KEYS
GROUPI  **  GRASS 4
ASSEMB  **  GRASS 4
SUBASS  **  SUBCOM 4
COMPON  **  SUBCOM 4
RAWMAT  **  SUBCOM 4
PANEL   **  PANEL 4
FRAME   **  FRM 4
VENEER  **  VNR 4
LAMINA  **  LAM 4
N3LAYE  **  3LY 4
;;CODE
GROUPI  +A0-
ASSEMB  +B0-
RAWMAT  +E0-
OVERHE  +C0-
VERTIC  +C1-
KNEEHO  +C2-
CURVED  +C3-
LANKIT  +C4-
WORKSA  +C5-
VDTSUR  +C6-
EXTENS  +C7-
```

```
BRIDGE   +C8-
PRINTE   +C9-
FRAME    +D1-
VENEER   +D2-
LAMINA   +D3-
N3LAYE   +D4-
EDGEBA   +D5-
INSERT   +D9-
;;END

C:\DCLASS>
```

```
type partc3.src
;;SUBTREE DM
;;//
;;// by H. Kim
;;// Aug. 15 1986
;;//
;;//
;;TREE
DIMENS.1.2      6  LENENT.2.1     ADDCOD.3.7     WIDENT.4.1     ADDCOA.5.7
                   THKENT.6.1     ADDCOB.7.7
;;TEXT
1   Dimension
2   LEN Enter length of part
3   ADD CODE &LEN 2.0 NO PERIOD
4   WID Enter width of part
5   ADD CODE &WID 2.0 NO PERIOD
6   THK Enter thickness of part
7   ADD CODE &THK 1.0 NO PERIOD
;;END

C:\DCLASS>
```

```
type partc4.src
;;SUBTREE MA
;;//
;;// by H. Kim
;;// Aug. 15 1986
;;//
;;//
;;TREE
MATERI.1.1     2  GROUPI.2      SUBASS.3
SUBASS.3.1     2  METAL.4       NONMET.5
NONMET.5.1     2  FIBROU.6      AMORPH.7
FIBROU.6.1     2  WOOD.8        TEXTIL.9
WOOD.8.1       3  NATURA.10     PROCES.11     CORK.12
NATURA.10.1    8  MAHOGA.13     OAK.14        WALNUT.15     CHERRY.16
                  MAPPLE.17     ELM.18        POPULA.19     OTHERS.20
PROCES.11.1    3  LAYERE.21     FIBROA.22     PARTIC.23
LAYERE.21.1    3  TECHGR.24     MICROL.25     OTHERB.26
PARTIC.23.1    2  PARTID.27     MOLDED.28
TEXTIL.9.1     2  NATURE.29     MANMAD.30
AMORPH.7.1     3  PLASTI.31     RUBBER.32     GLASS.33
PLASTI.31.1    2  SOLIDP.34     LAMINA.35
SOLIDP.34.1    3  CLEAR.36      SMOKED.37     OPAQUE.38
RUBBER.32.1    3  NATURF.39     SYNTHE.40     ELASTO.41
GLASS.33.1     2  COMMER.42     TECHNI.43
;;TEXT
1    Material
2    Grouping/Assembly
3    Subassembly/Component/Raw material
4    Metal
5    Non-metal
6    Fibrous material
7    Amorphous
8    Wood
9    Textile fiber
10   Natural wood
11   Processed wood
12   Cork
13   Mahogany
14   Oak
15   Walnut
16   Cherry
17   Mapple
18   Elm
19   Popular
20   Others
21   Layered/jointed wood
22   Fibrous-felted wood
23   Particle product
24   Techgrain
25   Micro-LAM
26   Others
27   Particle board
28   Molded wood
29   Natural fiber
30   Man-made fiber
31   Plastic
32   Rubber/Elastomer
33   Glass
34   Solid plastic
35   Laminate
36   Clear
37   Smoked
38   Opaque
39   Natural rubber
```

```
40  Synthetic rubber
41  Elastomer
42  Commercial glass
43  Technical glass
;;INPUT KEYS
GROUPI  **  GRASS
SUBASS  **  SUBCOM
;;CODE
GROUPI  +-00
METAL   +-A0
CORK    +-BN
MAHOGA  +-BA
OAK     +-BB
WALNUT  +-BC
CHERRY  +-BD
MAPPLE  +-BE
ELM     +-BF
POPULA  +-BG
OTHERS  +-BH
FIBROA  +-BL
TECHGR  +-BI
MICROL  +-BJ
OTHERB  +-BK
PARTID  +-BM
MOLDED  +-B0
NATURE  +-C1
MANMAD  +-C2
LAMINA  +-D4
CLEAR   +-D1
SMOKED  +-D2
OPAQUE  +-D3
NATURF  +-E1
SYNTHE  +-E2
ELASTO  +-E3
COMMER  +-G1
TECHNI  +-G2
;;END

C:\DCLASS>
```

```
type partc5.src
;;SUBTREE CL
;;//
;;// by H. Kim
;;// Aug. 15 1986
;;//
;;//
;;TREE
COLOR.1.1      3  NOTSPE.2    PANEL.3     METAL.4
PANEL.3.1      3  VENEER.5    LAMINA.6    FABRIC.7
VENEER.5.1     4  NATURA.8    RED.9       BROWN.10    OTHERS.11
RED.9.1        3  LIGHT.12    MEDIUM.13   DARK.14
BROWN.10.1     4  LIGHTA.15   MEDIUB.16   DARKC.17    ENGLIS.18
LAMINA.6.1     8  WHITE.19    BEIGE.20    GRAY.21     BLACK.22
                  SLATE.23    AMARAN.24   PEACH.25    TAUPE.26
GRAY.21.1      3  LIGHTD.27   MEDIUE.28   DARKF.29
;;TEXT
1    Color
2    Not specified
3    Panel
4    Metal
5    Veneer panel
6    Laminate panel
7    Fabric panel
8    Natural
9    Red
10   Brown
11   Others
12   Light
13   Medium
14   Dark
15   Light
16   Medium
17   Dark
18   English
19   White
20   Beige
21   Gray
22   Black
23   Slate
24   Amaranto
25   Peach
26   Taupe
27   Light
28   Medium
29   Dark
;;INPUT KEYS
PANEL    **  PANEL
VENEER   **  VNR
LAMINA   **  LAM
;;CODE
NOTSPE   +00
METAL    +D0
FABRIC   +C0
NATURA   +A1
OTHERS   +A9
LIGHT    +A2
MEDIUM   +A3
DARK     +-A4
LIGHTA   +A5
MEDIUB   +A6
DARKC    +A7
ENGLIS   +A8
WHITE    +B1
```

```
BEIGE    +B2
BLACK    +B6
SLATE    +B7
AMARAN   +B8
PEACH    +B9
TAUPE    +B0
LIGHTD   +B3
MEDIUE   +B4
DARKP    +B5
;;END

C:\DCLASS>
```

```
type partc6.src
;;SUBTREE FI
;;//
;;// by H. Kim
;;// Aug. 15 1986
;;//
;;//
;;TREE
FINISH.1.1      3  NOTSPE.2        AGRADE.3        BGRADE.4
;;TEXT
1   Finish
2   Not Specified
3   A grade
4   B grade
;;CODE
NOTSPE  +0-
AGRADE  +1-
BGRADE  +2-
;;END

C:\DCLASS>
```

```
type partc7.src
;;SUBTREE FM
;;//
;;// PROCESSES FOR FRAME
;;// by H. Kim
;;// Aug. 20 1986
;;//
;;//
;;TREE
FRAME.1.2      3  STANDA.2    STUFFI.3    SPECIA.4
STANDA.2.1     2  ROUGHC.5    NONSTA.6
STUFFI.3.1     2  STUFFV.7    NOVERT.8
SPECIA.4.1     3  BOREHO.9    OTHERO.10   NOSPEC.11
BOREHO.9.1     2  VERTIC.12   HORIZO.13
;;TEXT
1   Frame
2   Standard process
3   Stuffings
4   Special operations
5   Rough cut/joint/rip/mold & plane/cut/assemble
6   Non-standard
7   Stuff verticel
8   No verticel
9   Bore holes in rails
10  Other operation(s)
11  No special operation
12  Vertical
13  Horizontal
;;CODE
ROUGHC  +1
NONSTA  +0
STUFFV  +1
NOVERT  +0
OTHERO  +3
NOSPEC  +0
VERTIC  +1
HORIZO  +2
;;END

C:\DCLASS>
```

```
type partc8.src
;;SUBTREE VP
;;//
;;// by H. Kim
;;// Aug. 20'1986
;;//
;;//
;;TREE
VENEER.1.2      6  PREPAR.2      PRESSP.3      EDGEBA.4      FINISH.5
                   BORING.6      SPECIA.7
PREPAR.2.1      2  CUTLEN.8      NONSTA.9
CUTLEN.8.1      2  BOOKMA.10     REVERS.11
PRESSP.3.1      2  PRESSM.12     NONSTB.13
EDGEBA.4.1      2  TRIMEB.14     NONSTC.15
FINISH.5.1      3  ROUGHS.16     HANDSA.17     NOFINI.18
BORING.6.1      3  VERTIC.19     HORIZO.20     NOBORI.21
SPECIA.7.1      4  ROUTIN.22     MORTIS.23     COMBIN.24     NOSPEC.25
ROUTIN.22.1     5  THROUG.26     HALFWA.27     PLUNGE.28     EDGERO.29
                   COMBID.30
;;TEXT
1   Veneer panel
2   Prepare veneers
3   Press panel
4   Edgeband
5   Finishing operation
6   Boring operation
7   Special operation
8   Cut length/shear width/splice
9   Non-standard
10  Bookmatch
11  Reverse slip match
12  Press MDF/Timesaver/Press veneer
13  Non-standard
14  Trim/EB(EB, radius, sand)
15  Non-standard
16  Rough sand/spray edge/coat top-bottom/sand/flat finish/wax
17  Hand sand/stain/second coat/hang finish
18  No finishing operation
19  Vertical
20  Horizontal
21  No boring operation
22  Routing
23  Mortise/rabbet/dovetail/miter
24  Combined above
25  No special operation
26  Through routing
27  Halfway routing
28  Plunge routing
29  Edge routing
30  Combined above
;;CODE
NONSTA  +0
BOOKMA  +1
REVERS  +2
PRESSM  +1
NONSTB  +0
TRIMEB  +1
NONSTC  +0
ROUGHS  +1
HANDSA  +2
NOFINI  +0
VERTIC  +1
HORIZO  +2
NOBORI  +0
```

```
MORTIS  +1
COMBIN  +9
NOSPEC  +9
THROUG  +2
HALFWA  +3
PLUNGE  +4
EDGERO  +5
COMBID  +8
;;END

C:\DCLASS>
```

```
type partc9.src
;;SUBTREE LP
;;//
;;// by H. Kim
;;// Aug. 20 1986
;;//
;;//
;;TREE
LAMINA.1.2     6  PREPAR.2     PRESSP.3     EDGEBA.4     FINISH.5
                  BORING.6     SPECIA.7
PREPAR.2.1     2  CUTLAM.8     NOPREP.9
PRESSP.3.1     2  COLDPR.10    NONSTA.11
EDGEBA.4.1     2  CUTEDG.12    NONSTB.13
FINISH.5.1     4  ROUGHS.14    SPRAYL.15    HANDOU.16    NOFINI.17
BORING.6.1     4  VERTIC.18    HORIZO.19    COMBIN.20    NOBORI.21
SPECIA.7.1     4  ROUTIN.22    MORTIS.23    COMBIC.24    NOSPEC.25
ROUTIN.22.1    5  THROUG.26    HALFWA.27    PLUNGE.28    EDGERO.29
                  COMBID.30
;;TEXT
1   Laminate panel
2   Prepare laminates
3   Press/postform
4   Edgeband
5   Finishing operation
6   Boring operation
7   Special operation(s)
8   Cut lam./cut backer
9   No-preparation
10  Cold press MDF/Timesaver/postform
11  Non-standard
12  Cut/edgeband
13  Non-standard
14  Rough sand/spray edge/coat top-bottom/sand/flat finish/wax
15  Spray laminate & bareboard
16  Hand out excess plastics (cleaning edges)
17  No finishing operation
18  Vertical
19  Horizontal
20  Combined above
21  No boring operation
22  Routing
23  Mortise/rabbet/dovetail/miter
24  Combined above
25  No special operation
26  Through routing
27  Halfway routing
28  Plunge routing
29  Edge routing
30  Combined above
;;CODE
CUTLAM  +1
NOPREP  +0
COLDPR  +1
NONSTA  +0
CUTEDG  +1
NONSTB  +0
ROUGHS  +1
SPRAYL  +2
HANDOU  +3
NOFINI  +0
VERTIC  +1
HORIZO  +2
COMBIN  +3
NOBORI  +0
```

```
MORTIS   +1
COMBIC   +9
NOSPEC   +0
THROUG   +2
HALFWA   +3
PLUNGE   +4
EDGERO   +5
COMBID   +8
;;END

C:\DCLASS>
```

```
type partc10.src
;;SUBTREE TP
;;//
;;// by H. Kim
;;// Aug. 20 1986
;;//
;;//
;;TREE
N3LAYE.1.2      7  PREPAR.2      EDGEBA.3      PARTPA.4      FINISH.5
                   BORING.6      ROUTIN.7      SPECIA.8
PREPAR.2.1      2  CUTLEN.9      NONSTA.10
EDGEBA.3.1      2  CUTEBE.11     NONSTB.12
PARTPA.4.1      2  PART.13       NOPART.14
FINISH.5.1      2  SANDFA.15     NOSAND.16
BORING.6.1      4  VERTIC.17     HORIZO.18     BOTHVE.19     NOBORI.20
ROUTIN.7.1      6  THROUG.21     HALFWA.22     PLUNGE.23     EDGERO.24
                   COMBIN.25     NOROUT.26
SPECIA.8.1      4  MORTIS.27     GLUEPU.28     BOTH.29       NOSPEC.30
;;TEXT
1    3-layer ply panel
2    Prepare panel
3    Edgeband
4    Part panel
5    Finishing operation
6    Boring operation
7    Routing operation
8    Special operation(s)
9    Cut length/shear width/splice/hot press
10   Non-standard
11   Cut EB/Edgeband
12   Non-standard
13   Part
14   No part
15   Sand faces/edges/pulls
16   No sanding operation
17   Vertical
18   Horizontal
19   Both vertical and horizontal
20   No boring operation
21   Through routing
22   Halfway routing
23   Plunge routing
24   Edge routing
25   Combined above
26   No routing operation
27   Mortise/rabbet/dovetail/miter
28   Glue pulls
29   Both
30   No special operation
;;CODE
CUTLEN   +1
NONSTA   +0
CUTEBE   +1
NONSTB   +0
PART     +1
NOPART   +0
SANDFA   +1
NOSAND   +0
VERTIC   +1
HORIZO   +2
BOTHVE   +9
NOBORI   +0
THROUG   +1
HALFWA   +2
```

```
PLUNGE   +3
EDGERO   +4
COMBIN   +9
NOROUT   +0
MORTIS   +1
GLUEPU   +2
BOTH     +9
NOSPEC   +0
;;END

C:\DCLASS>
```

Appendix A.11

```
 Enter ID #
>>

 Family selection
 1 - General
 2 - Designer's system
 3 - Seatings
 4 - Desks & Tables
**>2

 Designer's system
 1 - Morrison
 2 - Zapf
 3 - New Hannah
 4 - Stephens
**>2

 Production level & Function
 1 - Grouping
 2 - Assembly
 3 - Subassembly
 4 - Component
 5 - Raw material
**>3

 Subassembly
 1 - Panel
 2 - Worksurface
 3 - Overhead shelf
**>2

 Worksurface
 1 - Worksurface
 2 - VDT surface
 3 - Extension
 4 - Bridge surface
 5 - Printer surface
**>1

 Enter length of part
>>43.25

 Enter width of part
>>18.25

 Enter thickness of part
>>1.25

 Material
 1 - Grouping/Assembly
 2 - Subassembly/Component/Raw material
**>2

 Subassembly/Component/Raw material
 1 - Metal
 2 - Non-metal
**>2

 Non-metal
 1 - Fibrous material
 2 - Amorphous
**>1

 Fibrous material
```

1 - Wood
2 - Textile fiber
**>1

Wood
1 - Natural wood
2 - Processed wood
3 - Cork
**>1

Natural wood
1 - Mahogany
2 - Oak
3 - Walnut
4 - Cherry
5 - Mapple
6 - Elm
7 - Popular
8 - Others
**>5

Color
1 - Not specified
2 - Panel
3 - Metal
**>2

Panel
1 - Veneer panel
2 - Laminate panel
3 - Fabric panel
**>1

Veneer panel
1 - Natural
2 - Red
3 - Brown
4 - Others
**>2

Red
1 - Light
2 - Medium
3 - Dark
**>2

Finish
1 - Not specified
2 - A grade
3 - B grade
**>2

Process selection
1 - Frame
2 - Veneer panel
3 - Laminate panel
4 - 3-ply panel
**>2

Prepare veneers
1 - Cut length/shear/width/splice
2 - Non-standard
**>1

Cut length/shear/width/splice
1 - Book match

```
    2 - Reverse match
**>2

    Press panel
    1 - Press MDF/Timesaver/Press veneer
    2 - Non-standard
**>1

    Edgeband
    1 - Trim/EB(EB, radius, sand)
    2 - Non-standard
**>1

    Finishing operation
    1 - Rough sand/spray edge/coat top-bottom/sand/flat
        finish/wax
    2 - Hand sand/stain/second coat/hang finish
    3 - No finishing operation
**>1

    Boring operation
    1 - Vertical
    2 - Horizontal
    3 - No boring operation
**>2

    Special operation
    1 - Routing
    2 - Mortise/rabbet/dovetail/miter
    3 - Combined above
    4 - No special operation
**>2

    Choose Option
    1 - Review Choices
  * 2 - Continue
==>

    Code=ZFC5-43181-BEA31-211121
```

VITA

Heejoon Kim was born in Seoul, Korea in 1959. He completed his Bachelor of Science degree in Industrial Chemistry at Hanyang University in Seoul, Korea in 1983. He continued his education at Lehigh University to pursue a Master of Science degree in the Industrial Engineering Department with special interest in the manufacturing system. He is also currently enrolled in the College of Business and Economics of Lehigh University in pursuit of a second Masters degree in Business Administration. After graduation, he will begin working at Hyesung Industries. Mr. Kim is an associate member of IIE.